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A seventeen inch lightweight improved performance band track was developed for use on the Automotive Test Rig (ATR), a 14 ton amphibious vehicle, under contract to the David Taylor Naval Ship R&D Center. The track was designed utilizing corrosion resistant materials to perform in a marine environment. Using data obtained from a laboratory test, a track was fabricated and installed on a M113 surrogate test vehicle. The performance testing has shown the track's noise and rolling resistance performance advantages as compared to current block tracks. The track has completed 500 miles of endurance testing with no failures or performance problems.

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IMPROVED PERFORMANCE BAND TRACK PROGRAM

FINAL REPORT

APRIL 1985

PREPARED UNDER CONTRACT NO. N00167-82-C-0149

FOR

DAVID W. TAYLOR NAVAL
SHIP R&D CENTER
BETHESDA, MARYLAND 20084

SUBMITTED BY

AAI CORPORATION
P.O. BOX 6767
BALTIMORE, MARYLAND 21204

PREPARED BY S.W. Miller

S. Fox

APPROVED BY W.A. Webb

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Abstract

A 17-inch lightweight improved performance band track was developed for use on The Automotive Test Rig (ATR), a 14 ton amphibious vehicle, under contract to the David Taylor Naval Ship R&D Center. The track was designed utilizing corrosion resistant materials to perform in a marine environment. Using data obtained from a laboratory test, a track was fabricated and installed on a M113 surrogate test vehicle. The performance testing has shown the track's noise and rolling resistance performance advantages as compared to current block tracks. The track has completed 500 miles of endurance testing with no failures or performance problems.

1.0 INTRODUCTION AND SUMMARY

This report documents the design and development of a 17 inch wide band track for use on a 14 ton amphibious vehicle being developed by AAI Corporation under contract to the David Taylor Naval Ship Research and Development Center.

The basic wire link band track was developed by AAI in 1957. From 1957 to 1966, the track received extensive design, development, and testing effort by AAI under contracts for the U.S. Army Tank-Automotive Command. During its development and test, the band track has shown superior noise reduction, reduced transmission of vibration and shock loads, reduced rolling resistance, and weight savings compared to any current block track design. The ability of the track to meet the design life of 250 hours has been a major problem throughout its development. The major goals of this program were to improve the durability of the track and adapt the track for a marine environment.

To increase life, the following configuration changes were implemented:

- Track width was increased from 15 inches to 17 inches. This width increase allows the use of more load carrying wire loops effectively reducing the unit loading and contact stresses. The reduced contact stress should decrease wear at the wire loop to pin interface and thus increase track life.

- The use of headed pins with improved snap rings to prevent pin movement. In past designs, the pins have occasionally worked loose and migrated out of position severely reducing the ability of the track to transmit loads. The new pins should prevent migration.

- Redesign of the track block end connector to reduce stress levels and reduce stress concentration on the threaded boss. In conjunction with the adaptation for marine environment, the material heat treating process was changed to improve the control of material properties. On previous track tests end connector boss failures had occurred. These failures were attributed to poor casting and improper heat treating. The new material and new design will reduce stress concentration and improve manufacturability of the end connector.

- To adapt the track for a marine environment, each track component was investigated to improve its corrosion resistance without degrading its performance or life. During the test phase of this program, several different materials were evaluated and the optimum combination of load carrying ability, wear rates, and corrosion resistance were evaluated.

With this initial information, complete engineering drawings were issued and sufficient parts were purchased to assemble a 12.5 foot length for laboratory testing. A laboratory test machine using an idler and hydrostatically driven final drive with a 4000 lb. tensile load applied to the track was used to evaluate the viability of the new track configuration. As a result of this test, the following conclusions were reacned:

- All metal components performed satisfactorily.

- Carbon steel crossmembers should be used due to excessive wear on stainless version.

- The rubber compound should be 63 durometer.

- Sprocket design should provide 0.05 in. underpitched.

The design improvements indicated by testing were incorporated in the track design and parts for 1 full track and spares were ordered.

The track was then assembled and installed on a M113 at AAI and initial run-in and operational tests were performed. The vehicle was then shipped to Camp Pendleton. The track was tested on varying surfaces to 26.7 hours (500 miles). During the test, track blocks were removed at 100 mile intervals for testing at AAI. At the end of testing, the track did not show any significant degradation in performance or apparent wear. The blocks removed during the test were statically pull tested and showed no decrease in strength from new blocks tested. The track was removed from the vehicle and returned to AAI for future installation on the 14 ton amphibious vehicle.

The testing completed to date indicates the track should show a significant durability increase as compared to wire link track previously tested. The ability of the track to complete the full 250 hours can only be determined by further vehicle testing.

A total of 52 inner and 52 outer rubber molded blocks plus 26 crossmembers were delivered as spares for this test effort. At the end of testing only three outer blocks were replaced as damaged because of driving accidents. Test sample blocks and crossmembers were removed for evaluation at 100 mile increments and additional blocks were subjected to post test destructive testing. The remainder of the spare blocks are in storage for use to support further testing of the track.

2.0 TRACK DESIGN

The wire link band track consists of four blocks connected by a crossmember. Each block has several sections of wire mesh pinned together to form a continuous tensile connection. (See Figures 1, 2 and 3). The track strength, weight, and operational requirements were developed as follows.

2.1 Design Criteria

The design criteria determined the loads the track components will be designed to transmit. The criteria represent a simplification of the loads imposed on the track components and reflect the environment the track will operate in.

The track tensile force determines the size of the track band elements and has the largest overall effect on the track design. From TACOM TR No. 10613, August 1969, title "Track Design Study (Task No. 26) XM179, SP, 155mm, the Ultimate track load = 2X GVW/track. During track development at AAI in the early 1960's, 5X maximum tractive effort was used as a design criteria. For the ATR it was decided to use 5X tractive effort which was the more conservative approach. See Appendix A.

The track centerguide is integral with the crossmember. The centerguide keeps the track centered and supports the side load of the vehicle when it is operating on a slope. Per TACOM 10613 the center guide should transmit 1/4 C.V.W. applied perpendicular to the center guide at 3/4 of its height. This criteria was used on this track. See Appendix A for detail calculations.

The cross member transmits track tensile loads from the drive sprocket to the track bands, it also supports the track bands laterally and helps provide torsional rigidity when the track encounters an obstacle. To size this member the dynamic wheel forces are determined and applied to the crossmember as it would encounter an obstacle in a worst case loading. See Appendix A for detailed analysis.

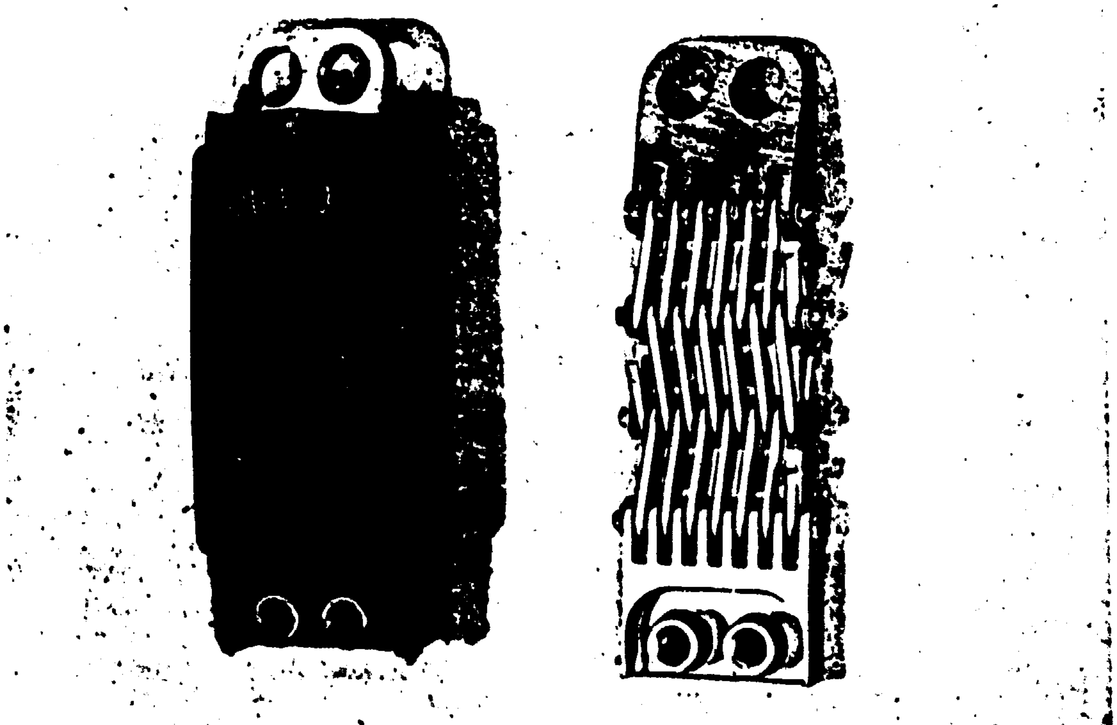

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Figure 1

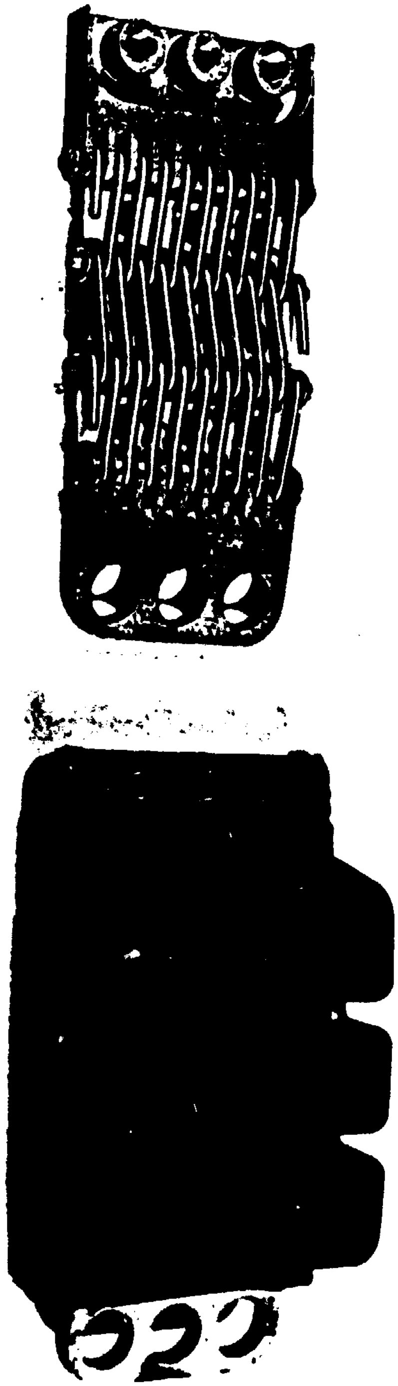

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Figure 2

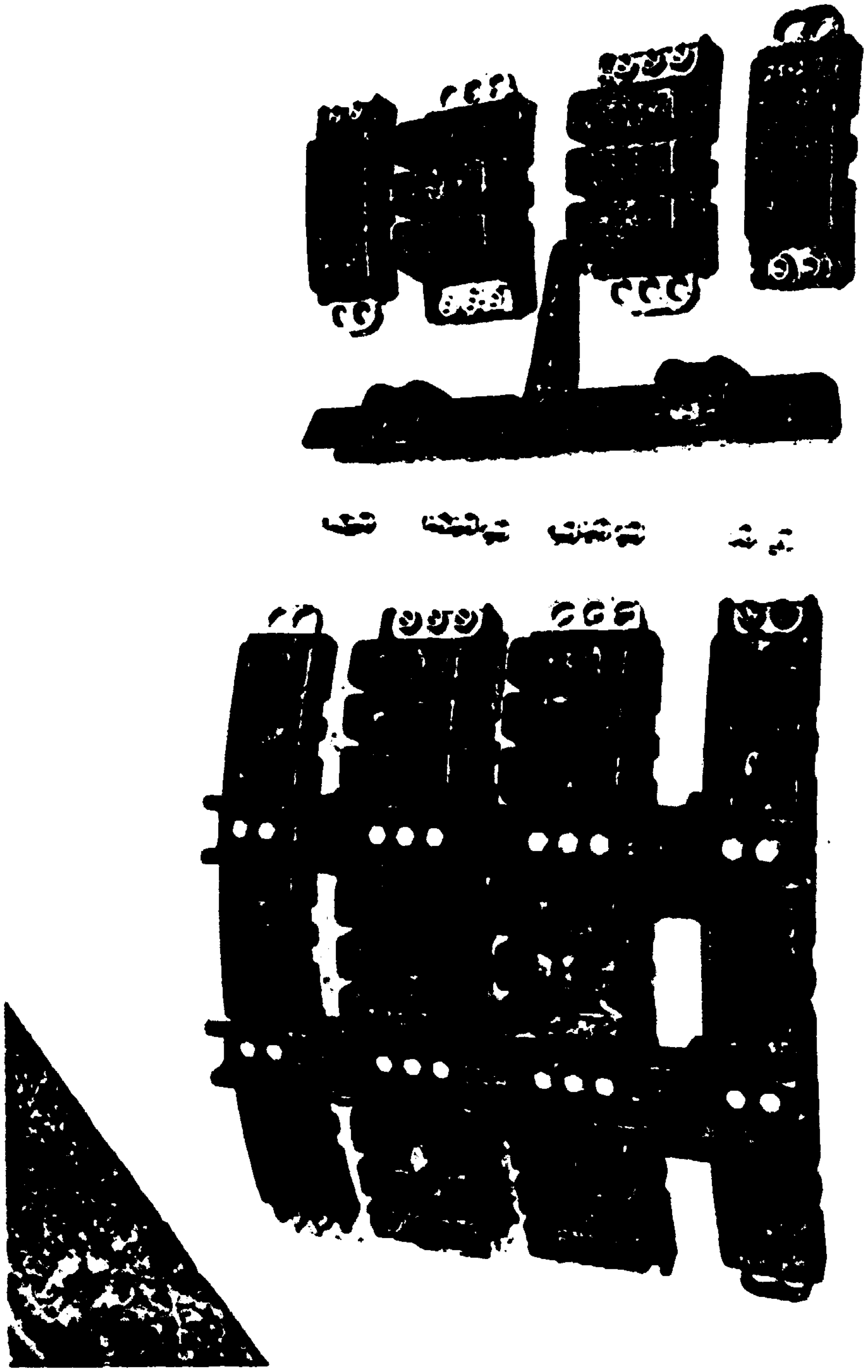

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Figure 3

2.2 Material Selection

On the original design of the T-139 band track the materials used were chosen without concern for corrosion resistance in a marine environment. A material investigation was performed to evaluate new materials for strength, wear, and corrosion resistance. This investigation is presented in Appendix B. As a result of this investigation and further lab testing the following materials were specified.

Component	Material
Wire Mesh Coil	Nitronic 60
Pin	440C
End Connector	15-5 PH
Cross member	4330
Spacer	5086-H32
Bolt	A286

The components have not shown any significant performance degradation as a result of corrosion in field testing to date.

2.3 Structural Analysis

Using the design criteria and material load bearing capabilities, each component's design was analyzed to determine its structural integrity. The optimum combination of weight, reliability, and performance for each component was investigated to provide an efficient and structurally sound track. The analysis applies the "worst case" combination of loads the track would be subjected to during its operation.

On several of the components analyzed the margin of safety is very small or a negative value. It was felt this was a result of the conservative nature of the design criteria and the analysis. The areas of concern were closely monitored during the test phase. The laboratory tests and vehicle tests have not shown any structural deficiencies to date. The detailed analysis is shown in Appendix C.

2.4 Weight Analysis

To further evaluate the advantages of the band track, the track design was analyzed to compare the weight with previous band and conventional tracks. As is shown in Appendix D, the analysis shows a significant weight advantage as compared to conventional block track designs. The weight savings will improve vehicle performance and increase the payload capability of the Automotive Test Rig.

3.0 LAB TEST

Upon completion of the design phase a section of track was fabricated for evaluation on a track test machine. See Figures 4 and 5. The machine applies tension to the track while it rotates, simulating the stretching and flexing the track components would encounter on a vehicle.

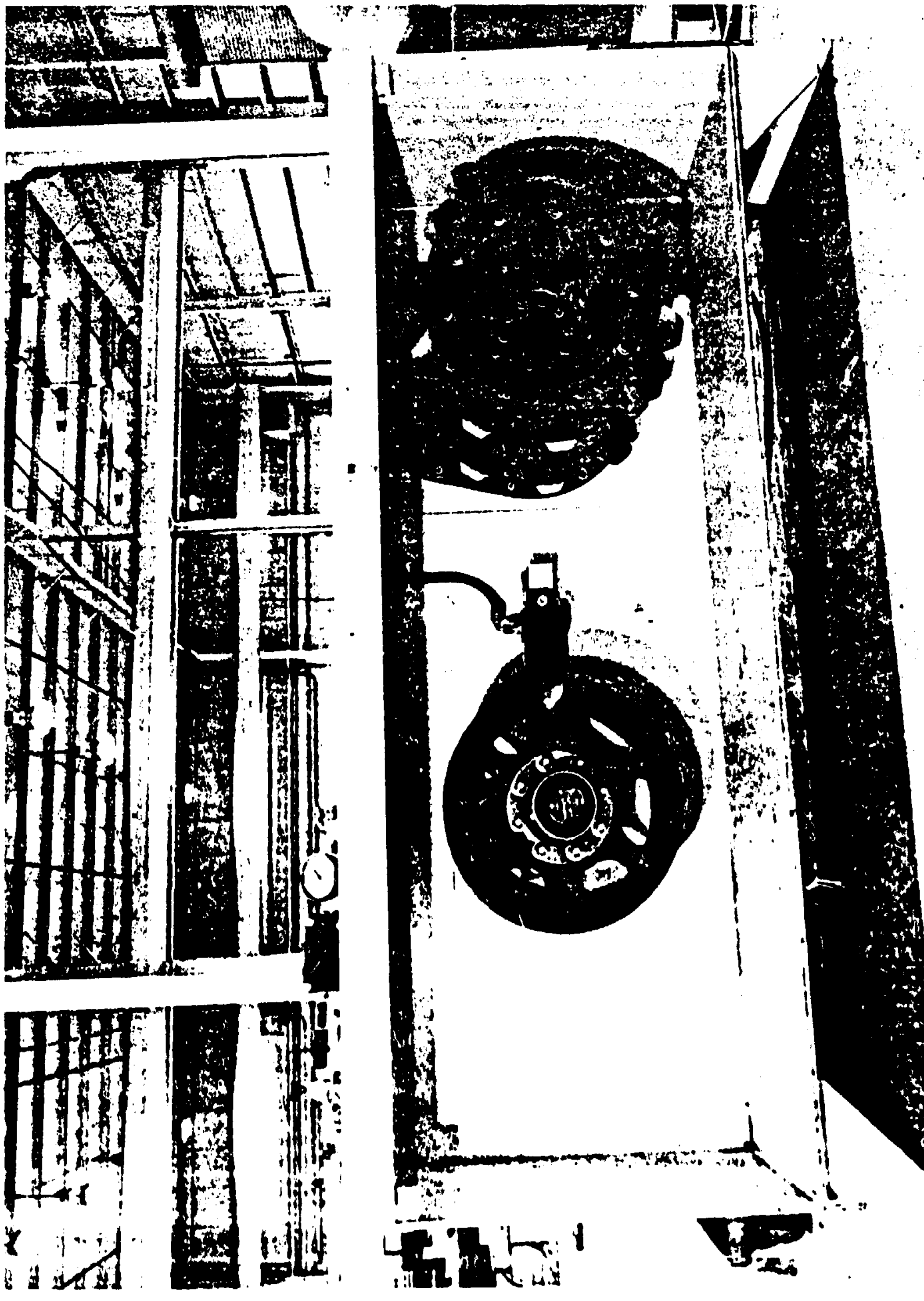

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Figure 4

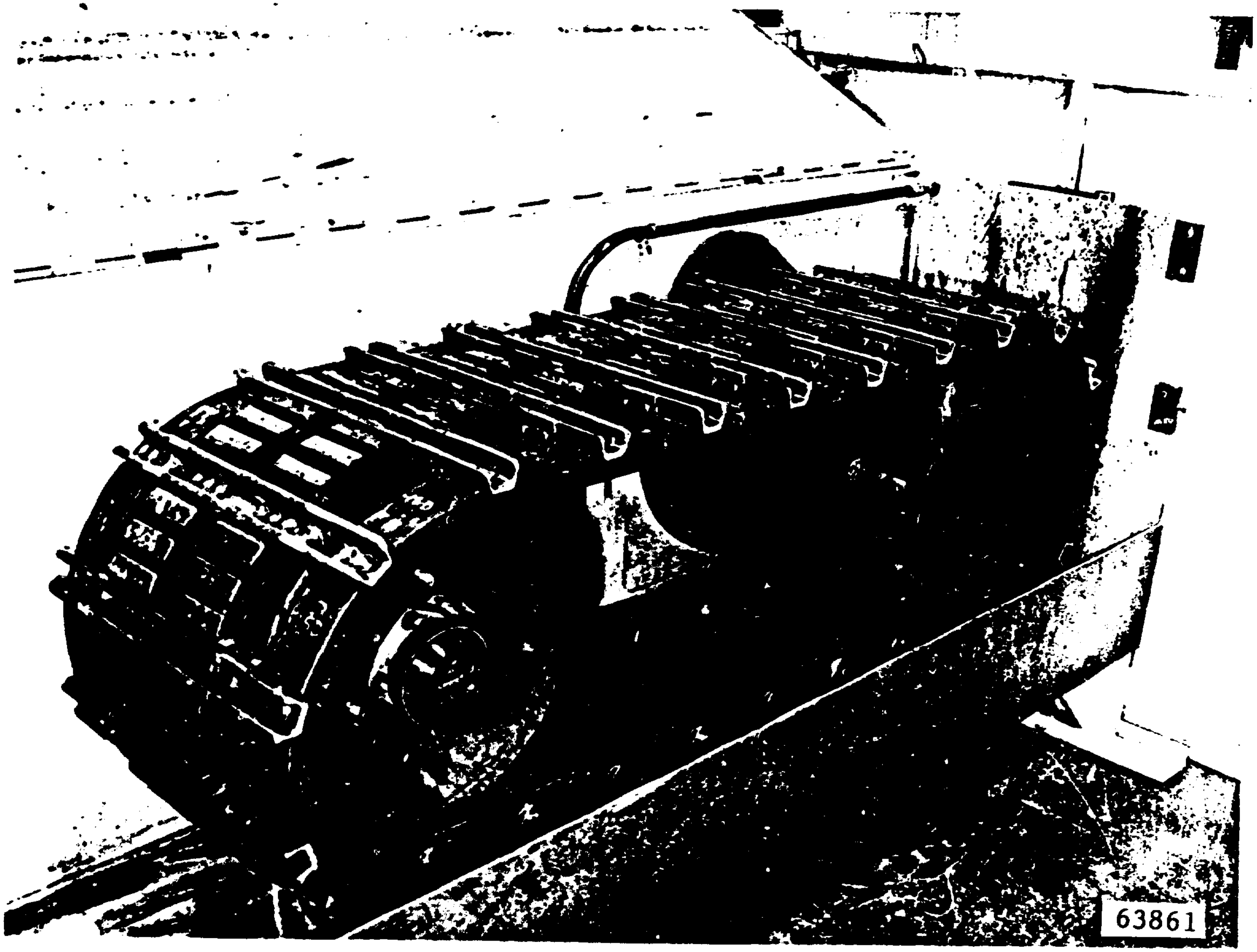

Figure 5

This test was used to evaluate the viability of the corrosion resistant materials and rubber compounds used on the track.

The results of this test reinforced the viability of the basic concept and indicated the need for further investigation of the rubber compounds. See Appendices E and F.

4.0 FIELD TEST OF TRACK COMPONENTS

Upon completion of the laboratory test, the improvements indicated by the test were implemented. The changes include, dimensional changes on the crossmember, the use of carbon steel for the crossmember, and the use of 63 durometer rubber. Parts were then ordered with sufficient spares to equip the M113 test vehicle. The track was assembled and installed on the M113 surrogate test vehicle for initial testing and evaluation. See Figures 6 and 7. The vehicle was operated for initial run-in and checkout testing at AAI then shipped to Camp Pendleton for further testing.

4.1 Field Test Data

The vehicle was tested at Camp Pendleton for 26.7 hours (500 miles) over sand, cross country, and paved surfaces. During the test, pitch length, pad wear, noise, and rolling resistance were measured. At 100 mile intervals several track sections were removed for further testing at AAI. The track completed its test with no significant degradation of performance or track failures.

4.2 Data Analysis

Pad Wear

As shown in Figure 8, the track pads have worn 0.08 inches during 500 miles of vehicle operation. Assuming the track continues to wear at this rate, the pad height would be reduced 0.64 inches at the end of 4,000 miles. This pad wear would not have a serious effect on the track life.

Rolling Resistance

During the testing of band track in the early 1960's the track showed a significant reduction in rolling resistance. The tests performed at Camp Pendleton on the M113 surrogate vehicle again demonstrated the improved rolling resistance as compared to current block tracks. See Figure 9. These improvements will result in improved vehicle performance and operating efficiency.

Noise

When the track elements are assembled it forms a continuous band of tensile elements encased in rubber. The band track has shown a significant reduction of track generated noise during previous tests. The noise tests performed at Camp Pendleton have again shown the reduced vehicle noise with the use of band track. The data collected during this test is shown in

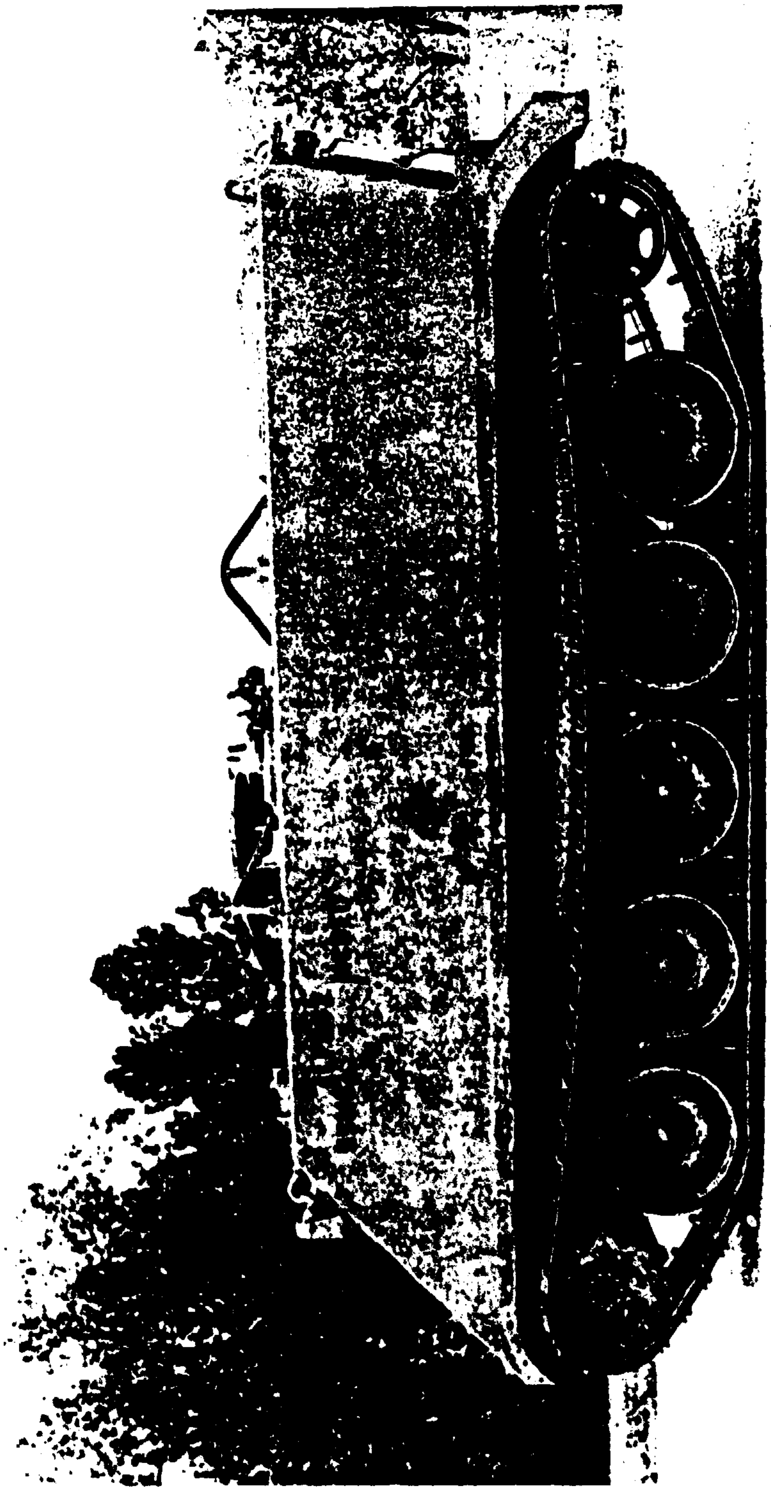

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Figure 6

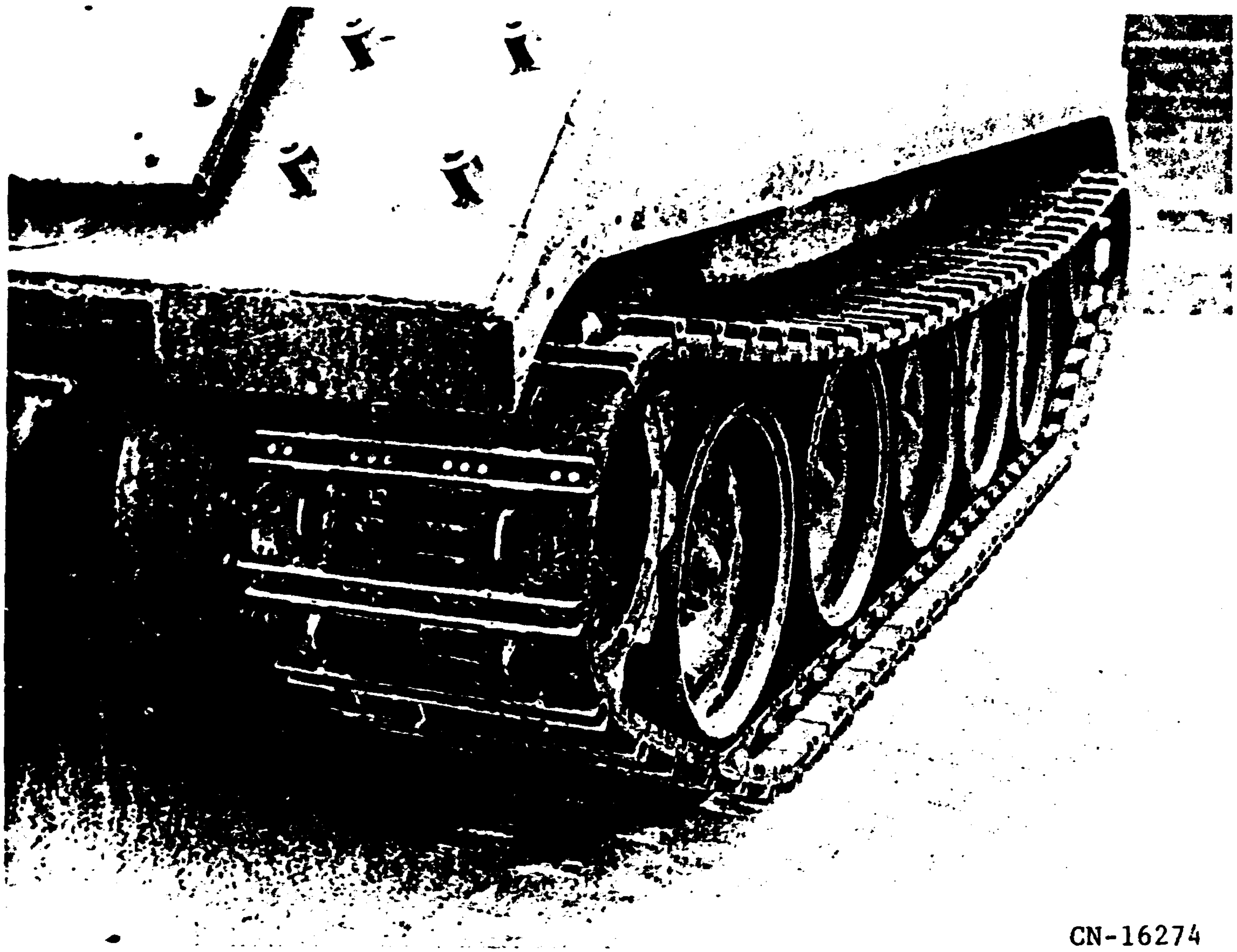

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Figure 7

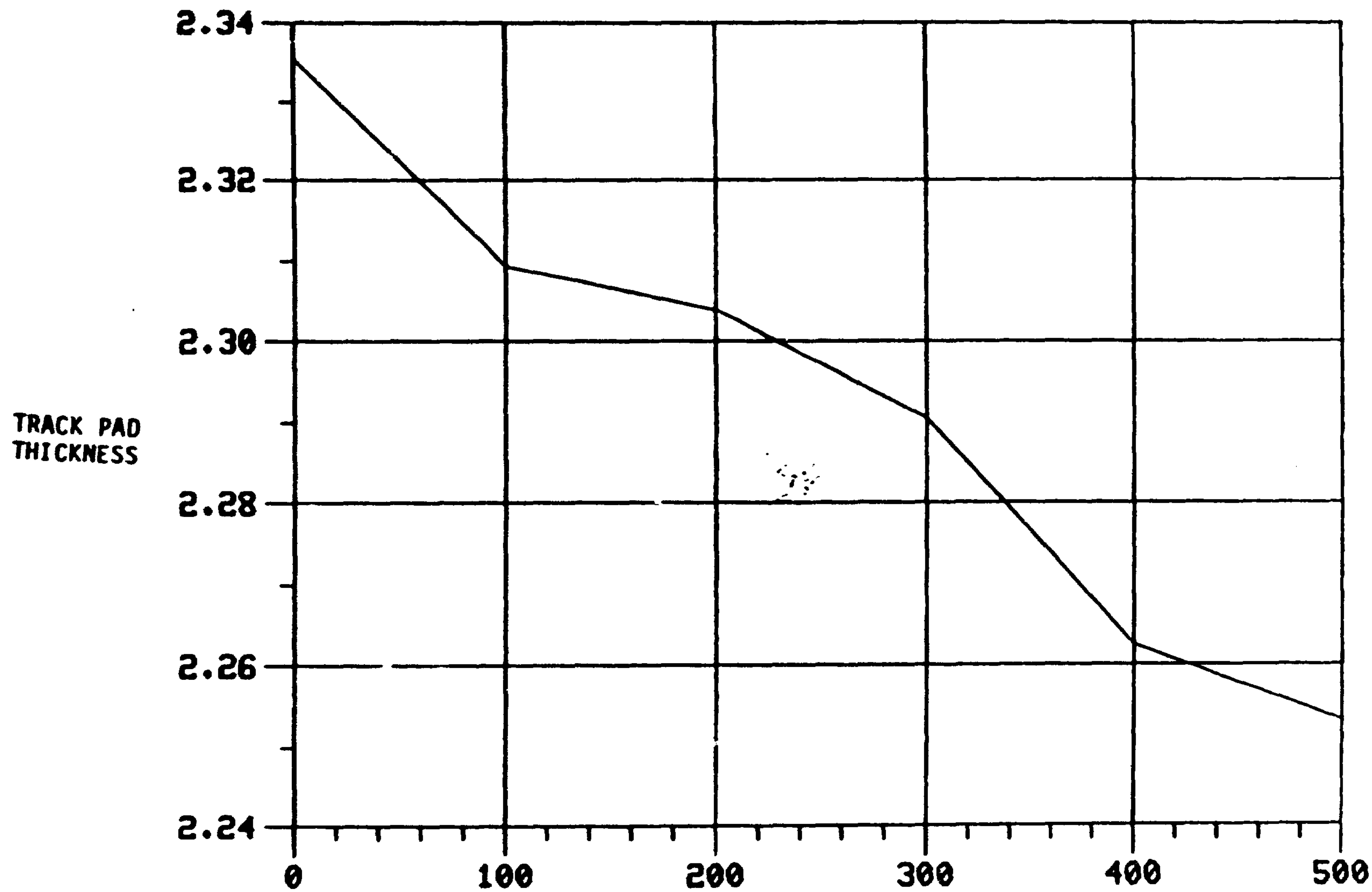


Figure 8

VEHICLE MILES, CAMP PENDLETON

Rolling Resistance

Camp Pendleton - 1984	Band
Sand	1600 lb.
Concrete	950 lb.

Aberdeen Proving Ground 1962	Band	Block
Concrete	859 lb	1047 lb

Noise Internal

Speed	Station	Block Track (1962)	Band Track (1984)
20 MPH	Driver	122 db	105.5 db
	Crew	120 db	112 db
10 MPH	Driver	116 db	104.5 db
	Crew	111.5 db	112 db

Figure 9

Figures 10 and 11. A brief comparison of band track and conventional track sound levels is shown in Figure 9. The reduced noise is a by-product of generally reduced vibration generated by the track. The reduced vibration and noise results in a vehicle that performs more effectively with less operator fatigue.

Pitch Elongation

Shown in Figure 12, the track stretch appears to correspond closely with results obtained on the test machine. This would indicate the track life will be limited by pitch elongation. Pitch elongation is the best overall indication of wear at the pin to wire junction. Wear at this connection will reduce the tensile strength of the track and eventually lead to track failure. Pitch elongation also limits the track useful life because of sprocket overpitching. As the pitch length increases the track will no longer mesh properly causing rough operation. From experience gained on the test machine the limit on pitch length is 5.925 inches. During the laboratory test when the track pitch reached this length the operation was very rough and track failure was impending.

Pull Tests

The blocks removed from the test vehicle were tested to determine the static strength capability. From the test results, see Figure 13, there appears to be no degradation of tensile strength capability that can be directly traced to accumulated miles. The pull test data does show an appreciable scatter or variation in the block strengths. This variation cannot be traced to any single element of the track. The accumulation of manufacturing and material tolerances is the most likely cause for the strength variation.

4.3 Failure Analysis

During the 500 miles of operation of this track there were no catastrophic failures of the track. During the course of the test, several blocks were damaged by striking an object of some type. The blocks were removed from the track to investigate the damage. These blocks were x-rayed at AAI. Of the blocks investigated only one showed any substantial damage. See Figure 14. It is estimated the block retained 2/3 of its original strength. The reduction of strength of this one block would not have impeded the operation of the track.

4.4 Life Projection

The life of the track cannot be absolutely predicted. The life of any track is dependent on the severity of the loads it encounters in its service life. As shown in Figure 12, the pitch length growth of the track tested on the M113 closely matches the growth shown on the laboratory test machine. Using this as a basis the track is expected to last 2000 miles. This is an estimate and the life could be increased depending on vehicle type of service encountered.

M113 External Noise

BW f_c

Speed mph	31.5	63	125	250	500	1K	2K	4K	8K	16K	31.5K	Composite
10			92	94	95.5	94.5	101.5	102	86	72	72	106
10			90	95	95	94	101	102	85	72	72	105.5
15			91	98	95	94.5	100.5	102	84.5	72	72	105.5
15			89	96	95	.95	101	102	84	72	72	105.0
20			87	98.5	95.5	95	101	102	84	72	72	105.5
20			85	97	95	94.5	101	100.5	83.5	72	72	105.5
25			91	99	97	95	101	101	83.5	72	72	106
25			89	100	96	95	100.5	101.5	84	72	72	105.5
30			90	100.5	99.5	96	101	101.5	84	72	72	106.5
30			91	98.5	95	96	101	101	84	72	72	106.5

Figure 10

15 Oct 84

M113 Internal Noise

Speed mph	Config. Ref Sta	Config. SRF	3.15	63	125	250	500	1K	2K	4K	8K	16K	31.5K	Composite
5	C	Pv	102.5	98.0	98	103	93	94.5	99.5	99.5	83			108
10			111	104.5	98.5	99.5	94	96.5	100.5	99.5	83			112
15			111.5	104.5	104.5	104.5	98	97	100	99.5	83			112
20			112.0	104.5	107.5	107.5	102.5	99.5	100	99.5	83			114
25			111.5	106.5	109.5	108.5	104	101.5	101	99	83			116
30	C	Pv	112.0	108.5	112	111	106	103	103	99.5	83			117.5
5	D	DT	87	89	97	93.5	92	93	99.5	100	83			104.5
10			88	89.5	96	94	92.5	92	99.5	100	83.5			104
15			90.5	90	96.5	93	93	93	99.5	100	83.5			104.5
20	D	DT	94	98.5	97	95.5	94.5	94.5	100	101	83.5			106
5	C		98.5	96.5	97.5	97.5	94	94.5	100.5	101	84			106.5
10			106	104	103	97.5	96	97	100.5	101	84			111.5
15			107	104.5	106	101	98.5	98	101	101	84			113
20	C	DT	107	108	107.5	104.5	101.5	100	101.5	101	84			114
10	D	Pv	92	90.5	97	93	93	93	100.5	101	84			104.5
15			90.5	90	98	92.5	93.5	93	100	101	84			105
20			88	91.5	97	93.5	94	93.5	100.5	101	84			105.5
25			88	95	98	94.5	95	97.5	101	101	84			106.5
30	D	Pv	88	100	105	100	103	101	104	101	84			102.5

Station C - Crew
D - Driver

Surface Pv - Pavement
DT - Dirt

Figure 11

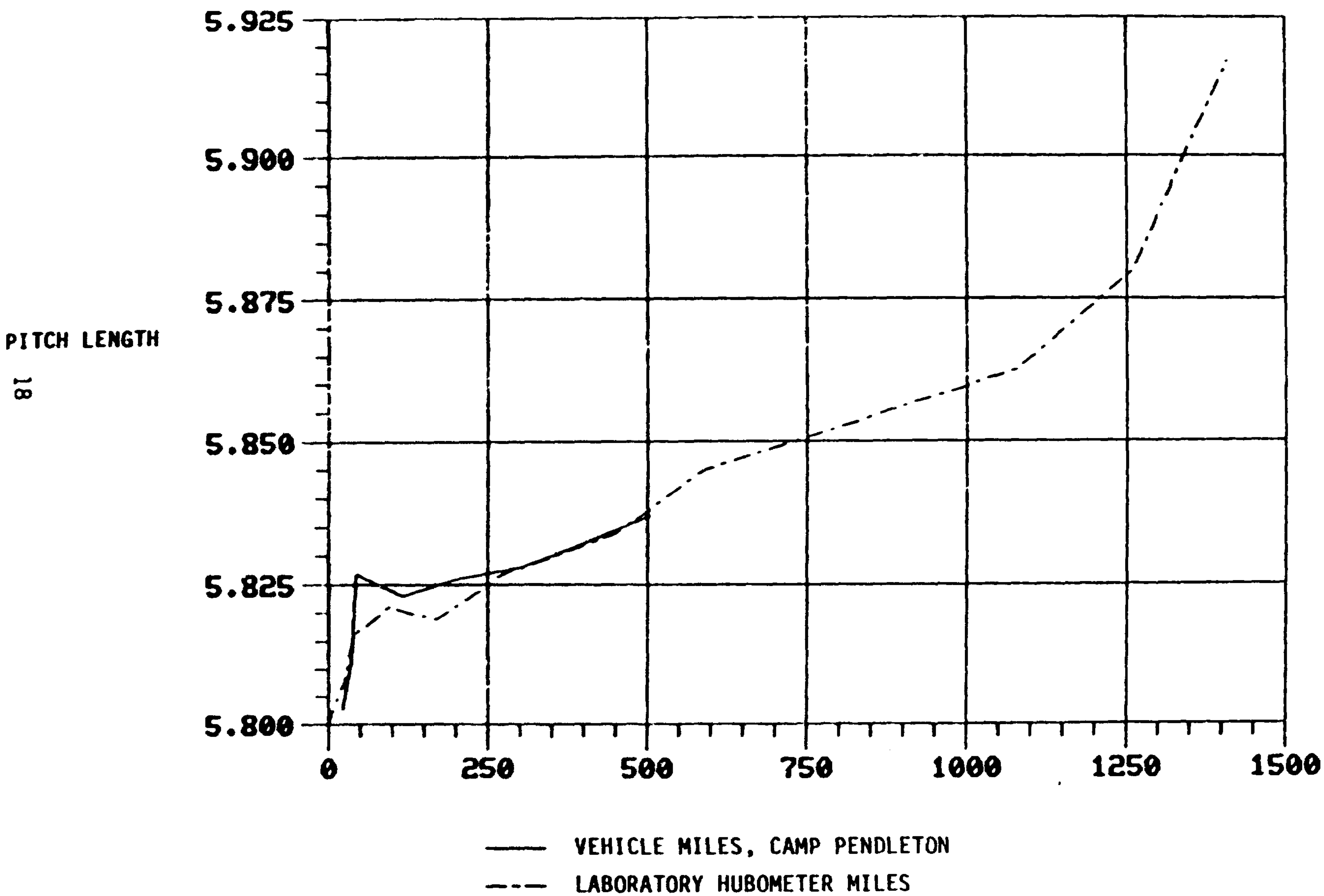

PITCH LENGTH
5.925
5.900
5.875
5.850
5.825
5.800
0
250
500
750
1000
1250
1500
VEHICLE MILES, CAMP PENDLETON
LABORATORY HUBOMETER MILES

Figure 12

LOAD CAPABILITY OF WIDE BAND TRACK ELEMENTS

SAMPLES FROM TEST VEHICLE AT CAMP PENDLETON

Miles	Ultimate Load
0	30,900 lb.
100	31,400 lb.
200	26,850 lb.
300	30,700 lb.
400	31,200 lb.
500	31,300 lb.

Figure 13

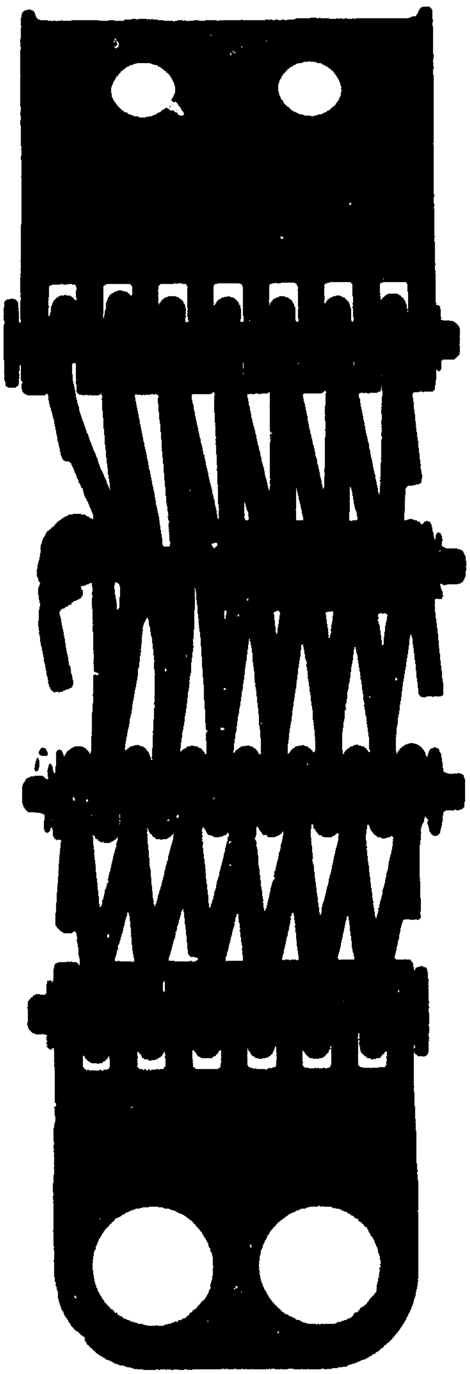


Figure 14
Damaged Block

5.0 CONCLUSIONS AND RECOMMENDATIONS

The tests and engineering investigations performed to date have verified the feasibility of the band track design. The track has completed 500 miles of testing with no incidence of track tensile failure or being thrown from the vehicle. Band track has shown significant performance advantages in weight noise, and rolling resistance. These performance advantages will allow the tracked vehicle to perform more efficiently and have increased survivability in a combat situation. The ability of the track to meet the desired life goals is still in question. From data received to date the track will last approximately 2000 miles on a 14-ton amphibious vehicle.

The problem of track life would indicate the need for further investigation of the primary flexible tension member. The major source of wear is the wire to pin junction. One possible way to reduce the wear would be to substitute roller chain as the tensile member.

6.0 PRODUCTION COST ESTIMATE

As part of this program, a production cost estimate has been prepared for the unit cost of the wire link track based on FY1982 dollars as specified in the contract. Production cost quotations have been obtained from qualified suppliers of each component part based on a production run of 1,000 sets of tracks assuming 70 feet of track per set. These quotations have been evaluated and an estimate made as to the "best and final" offer from each supplier. These costs are based on the drawings of the test track with no production engineering to reduce cost.

Using the AAI cost structure as a guide, each quotation has been burdened to include the following factors: (1) Procurement overhead @ 10%; (2) General and Administrative overhead @ 20%; and (3) Profit @ 10%. Also, these costs have been reduced by 10% to reflect the average CPI difference between FY1982 and current FY1985.

A summary of this cost estimation is included in the following two detailed analyses. The first listing shows the unit cost for each track component. It lists the quoted cost and source plus a best estimated cost followed by an extended unit price including overhead burdens. The second listing presents the unit cost of each component of one track section making up one six inch track pitch.

Based on this conservative cost approach, the wire link track is estimated to cost $172.47 per six inch pitch with an initial tooling cost of $213,132.

COMPONENT PRODUCTION COST ESTIMATE BASED ON 1,000 SETS OF TRACKS

Descriptions	Part No.	Vendor	Tooling	Quoted Unit Prices	Best Estimate Unit Prices	Extended Unit Prices*
Crossmember-Casting	40011	Silver Steel	$ 8,438	$24.00/ea.	20.00	26.14
Crossmember-Machining	40025	Simpson Mach.	3,200	6.75/ea.	5.00	6.53
End Connector-Male	40003-4	Consolidated	4,050	5.24/ea.	4.00	5.23
End Connector-Female	40004-4	Consolidated	3,820	4.83/ea.	3.50	4.57
End Connector-Male	40005-4	Consolidated	4,050	6.02/ea.	5.00	6.53
End Connector-Female	40006-4	Consolidated	4,050	5.45/ea.	4.50	5.88
Rubber Block-Narrow	40001-30	Goodyear	70,000	9.63/ea.	8.00	10.45
Rubber Block-Wide	40001-40	Goodyear	97,500	11.58/ea.	9.00	11.76
Male End Pin	40009-5	Gormak	594	1.26/ea.	1.00	1.31
Female End Pin	40009-6	Gormak	594	1.15/ea.	.95	1.24
Male End Pin	40009-7	Gormak	594	1.05/ea.	.90	1.17
Female End Pin	40009-8	Gormak	594	.98/ea.	.90	1.17
Wire Mesh Pin	40010-3	Gormak	594	1.20/ea.	1.00	1.31
Wire Mesh Pin	40010-4	Gormak	594	1.01/ea.	.90	1.17
Spacer-Narrow	40007	FFC	7,650	.23/ea.	.20	.26
Spacer-Wide	40008	FFC	6,810	.29/ea.	.25	.33
Wire Mesh-Narrow	40002-30	Wire Mesh Prod.	None	6.39/ea.	4.00	5.23
Wire Mesh-Wide	40002-40	Wire Mesh Prod.	None	8.92/ea.	6.00	7.84
Washer	AN960-XC10L	MS Inserts	None	.005/ea.	.005	.006
Retaining Ring	MS16633-4018	MS Inserts	None	.033/ea.	.033	.043
Bolts	MS90725-59	MS Inserts		.064/ea.	.064	.084

* 10% reduction to reflect FY82 costs, 10% procurement overhead, 20% General and Administrative overhead, 10% profit

PRODUCTION COST ESTIMATE PER SECTION (6" PITCH)

Description	Part No.	Quantity/Pitch	Unit Price	Price/Pitch
Crossmember-Casting	40011	1	26.14	26.14
Crossmember-Machining	40025	1	6.53	6.53
End Connector-Male	40003-4	2	5.23	10.46
End Connector-Female	40004-4	2	4.57	9.14
End Connector-Male	40005-4	2	6.53	13.06
End Connector-Female	40006-4	2	5.88	11.76
Rubber Block-Narrow	40001-30	2	10.45	20.90
Rubber Block-Wide	40001-40	2	11.76	23.52
Male End Pin	40009-5	2	1.31	2.62
Female End Pin	40009-6	2	1.24	2.48
Male End Pin	40009-7	2	1.17	2.34
Female End Pin	40009-8	2	1.17	2.34
Wire Mesh Pin	40010-3	4	1.31	5.24
Wire Mesh Pin	40010-4	4	1.17	4.68
Spacer-Narrow	40007	6	.26	1.56
Spacer-Wide	40008	6	.33	1.98
Wire Mesh-Narrow	40002-30	2	5.23	10.46
Wire Mesh-Wide	40002-40	2	7.84	15.68
Washer	AN960-XC10L	8	.006	.05
Retaining Ring	MS16633-4018	16	.043	.69
Bolt	MS90725-59	10	.084	.84

Appendix A

A. Design Criteria

Background

The T-139 track, designed, built and tested by AAI in the early 1960's was designed using the following design criteria.

1. Best strength to weight ratio

2. The minimum tensile strength would be five times the force the power plant can deliver to the track

From TACOM TR No. 10613, August 1969, Title "Track Design Study (Task No. 26) XM179, S.P., 155mm the following criteria was used.

1. Ultimate track load = 2 x GVW/Track

2. Ruber bushing load = GVW x $f_f/2$

3. Center guide strength calculate with 1/4 GVW applies perpendicular to the center guide at 3/4 of total center guide height.

4. Pad pressure calculated as GVW/wheels

The 17 in wide band track is intended for use on a 14 ton tracked amphibian. The amphibian will have a total of 5 dual wheel stations per vehicle side. The wheel width will be 3.00 in. The maximum final drive output torque is expected to be 10,000 ft-lbs. The pitch diameter of the drive sprocket is 18.79 inches.

1. Ultimate Tensile Capacity, P_T

The ultimate tensile capacity must be greater than the 5 times the maximum tractive effort or 2 times the GVW, whichever is greater.

$$P_T = \frac{5 \times 10{,}000 \text{ [ft-lbs]}}{\frac{18.79}{2 \times 12}} = 64000 \text{ lbs}$$

or

$$P_T = 2 \times 28000 = 56{,}000 \text{ lbs}$$

then

$$P_T = 64{,}000 \text{ lbs}$$

2. Center Guide Lateral Capacity, P_L

The center guide must be capable of withstanding 1/4 of the GVW applied perpendicular to the center guide at a distance of 3/4 of the total center guide height.

$$P_L = .25 \times 28000$$

$$P_L = 7000 \text{ lbs}$$

3. Impact Force Experienced by Crossmember, P_V

To find the vertical impact force experienced by the cross-member on an ATR vehicle redo the dynamic analysis of 11/15/82 using ATR characteristics rather than M113A2.

Dynamic Analysis (Forces on a Road Wheel Striking an Obstacle)

The maximum loads applied to a military vehicle, are dynamic loads. These loads are characterized by high shocks induced by rough terrain, by obstacles in the vehicle's path, and by the firing of heavy weapons. These forces are difficult to evaluate accurately. Using the principles of momentum, the following equations can be derived. This analysis is presented in AMCP 706-357 Automotive Bodies and Hulls.

$$Fx \quad t = M (v_{x2} - v_{x1})$$

$$To \quad t = Io (W_2 - W_1)$$

where:

x = Displacement in any direction, ft

Fx = Force component in the given direction x, lb

t = Duration of the impact; sec

M = Mass of the body concerned, lb-sec^2/ft

v_{x2}, v_{x1} = Final and initial velocities, respectively, of the body in the direction x, fps

To = Turning moment about an axis 0, ft-lb

Io = Mass moment of inertia of the body about axis 0, ft-lb-sec^2

W_2, W_1 = Final and initial angular velocities, respectively, of the body, rad/sec

Applying the above principle to the forward roadwheel of a tracked vehicle, the following relationships are arrived at:

$$Fx = \frac{Mv^2\ (\cos \theta - 1)}{R\theta}$$

where: R = Rolling radius of wheel

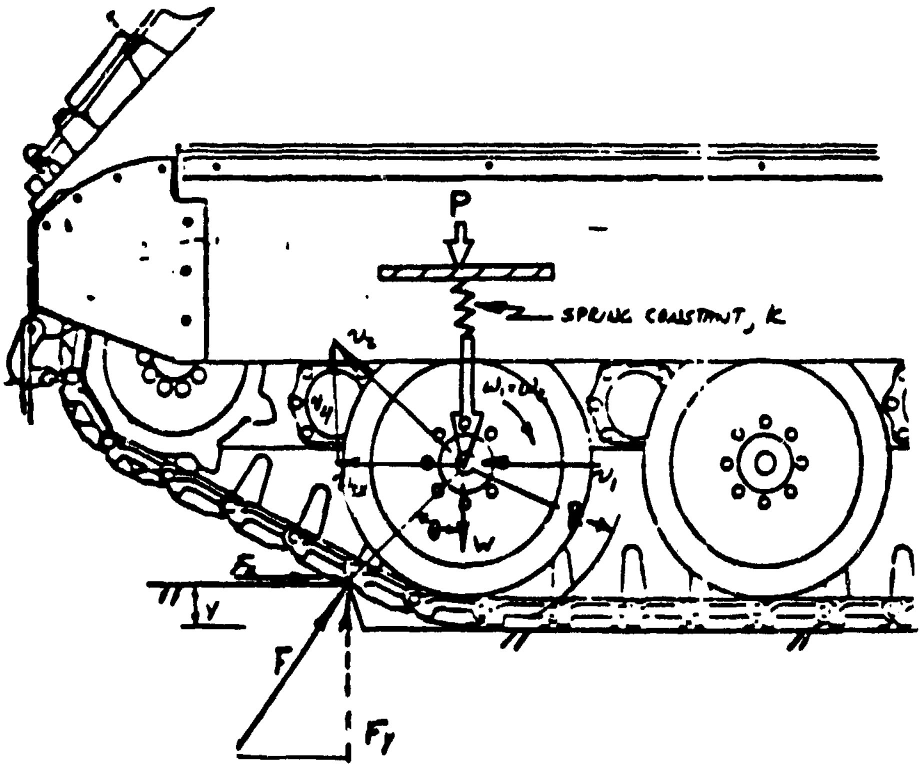
$$F_y = \frac{Mv \sin \theta}{R\theta} + P + W + ky$$

where:

P = Static load carried by the wheel

W = Weight of the wheel assembly

Ky = Maximum downward force developed by the spring system as the wheel rises over the obstacle



Driver ride limited speed for the ATR has been approximated in Figure 1. The criteria for the speed-obstacle relationship is two and a half G's at the driver's station. This mobility data is used to determine the roadwheel impact loads on an obstacle. Using Figure 1 the following ride limited speed for obstacles is:

Obstacle Height (inches)	Speed (MPH)
10	45.0
10.5	35.0
11	25.0
12	20.5
13	16.0

The following ATR vehicle characteristics are:

GVW = 14 ton

Roadwheel Diameter: 22 inches, 10 stations

Track Tnickness: 2.38 inches

Sprung Weight:

$$W_{SP} = GVW - 1/2\,(W_{track} + W_{roadarms})$$
$$- W_{hubs} - W_{roadwheels}$$
$$= 28000 - 1/2\,(2250 + 259.6)$$
$$-161.94 - 856$$
$$= 25727.3 \text{ lbs}$$

weight distribution x even

jounce capacity = 15 inches

spring rate of suspension unit

$$K = \frac{2\,(25727.3)}{10 \times 15} = 343 \text{ lbs/in}$$

Effective weight of wheel, 1/2 roadarm and hub

$$W_{eff} = 85.6 + 1/2\,(29.96) + (13.58 + 2.61)$$
$$= 116.8 \text{ lbs}$$

Calculate the impact force experienced by the ATR front roadwheel using the characteristics above.

K·E 20 X 20 TO THE INCH · KEUFFEL & ESSER CO.

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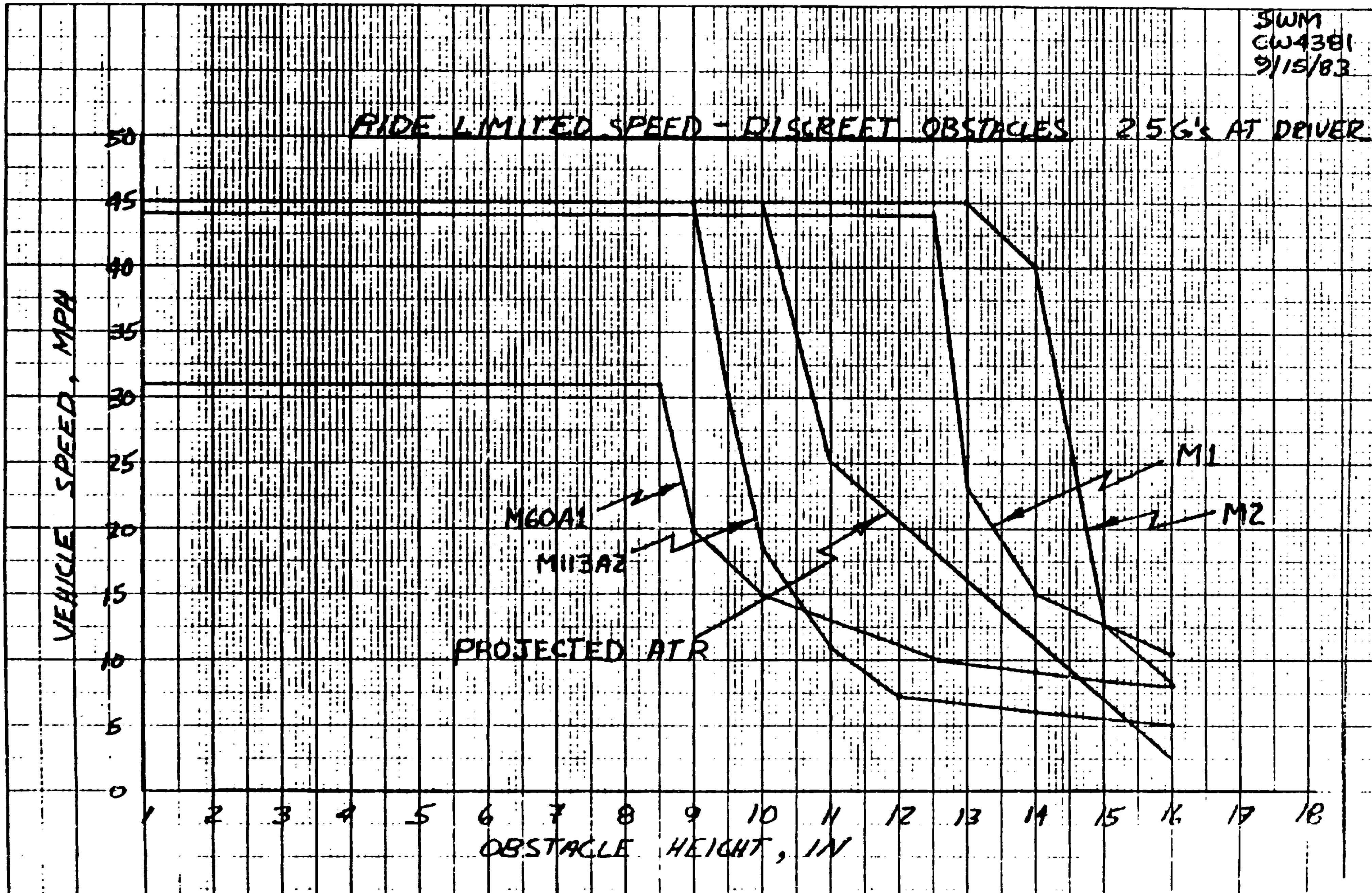


FIGURE 1

$$P = \frac{W_{sp}}{10} = \frac{25730}{10} = 2573 \text{ lbs}$$

$$W = 117 \text{ lbs}$$

$$M = \frac{W}{g} = \frac{117}{32.2} = 3.63 \text{ lbs-sec}^2/\text{ft}$$

$$I_o = \frac{Md^2}{16} = \frac{3.63 \times (22)/12)^2}{16}$$

$$= .763 \text{ ft-lbs-sec}^2$$

$$R = 22/2 + 2.38 = 13.38 \text{ inches}$$
$$= 1.115 \text{ feet}$$

$$K = 343 \text{ lbs/in} = 4116 \text{ lbs/ft}$$

y = 10, 10.5, 11, 12, 13 [in]
= .83, .88, .92, 1.0, 1.08 [ft]

v = 45, 35, 25, 20.5, 16 [mph]
66, 51.3, 36.7, 30.1, 23.5 [ft/sec]

$$\theta = \text{arc cos } \frac{(R-Y)}{R}, \text{ where } R = 1.115 \text{ ft}$$

Y, (feet)	θ (rad)
.83	1.312
.88	1.358
.92	1.400
1.00	1.467
1.08	1.539

$$F_x = \frac{Mv^2 (\cos \theta - 1)}{R\theta}$$

$$F_y = \frac{M\,v\,\sin\theta}{R\theta} + P + W + KY$$

where: $M = 3.63$ lbs-sec^2/ft
$R = 1.115$ ft
$P = 2573$ lbs
$W = 117$ lbs
$K = 4116$ lbs/ft
y
v
θ

Obstacle Height (ft) Y	Speed (ft/sec) v	θ (rad) θ	Force in X Direction (Lbs) Fx	Force in Y Direction (Lbs) Fy	Total Force (Lbs) F
.83	66	1.312	-8215.8	6662.0	10577
.88	51.3	1.358	-5083.7	6874.5	8550
.92	36.7	1.400	-2655.7	7038.9	7523.1
1.00	30.1	1.467	-1841.1	7423.3	7648.2
1.08	23.5	1.539	-1155.4	7808.6	7893.6

From the above table it can be concluded that the maximum road wheel force developed occurs at the maximum speed of 66 ft/sec or 45 mph. This load will be assumed to be transmitted through the crossmember. Therefore, P_v will be taken as 10,600 lbs.

$P_v = 10600$ lbs

Design Criteria Summary

Ultimate Tensile Capacity, P_T

$P_T = 64{,}000$ lbs

Center Guide Lateral Capacity, P_L

$P_L = 7000$ lbs*

* Applied to the center guide perpendicular to the spike at a distance of 3/4 of the total center guide height.

Impact Force Experienced by Crossmember, P_v

P_v = 10,000 lbs

Appendix B

IFSTT Material Investigation

Introduction

The metal components selected for the Initial Full Scale Test Track (IFSTT), to be fabricated during the scope of this contract, must be chosen on the basis of saltwater environment suitability, structural adequacy, fabricability, and cost. This investigation addresses these requirements and provides material options for each component.

The IFSTT design is a modification of the T-139 test track which was designed and fabricated by AAI Corporation in the early 1960's. Four test tracks were fabricated and tested during this development effort. Each track tested provided valuable information which was used to improve the following track.

The materials selected for use on the T-139 were chosen without concern for saltwater environment suitability. Through extensive testing and evaluation, the materials used on the final T-139 track provided an excellent balance of structural adequacy, fabricability, and cost. Table A lists the materials used for fourth and final T-139 track. These materials will be used as the baseline from which corrosion resistant material options will be evaluated.

Table A. Material Used for the T-139 Track Components

Component	Material
Wire Mesh Coil	AISI 6150
Pin	AISI 8640
End Connector	AISI A4330
Crossmember	AISI 4330
Spacer	2023-T3
Bolt	Medium carbon alloy steel (Grade 8)

Corrosion Resistance Requirements

The behavior of materials may vary widely, depending on the saltwater exposure condition. For the purposes of this investigation the components of the IFSTT are assumed to operate while immersed in seawater for limited periods of time. Additionally, the track will be subjected to mistladen sea air for extended periods of time. These two conditions are considered to be the most severe saltwater environments in which the track will operate. The components which are contained in the rubber molded assembly are not assumed to be isolated from the saltwater environment. There is a possibility of seepage through small cracks that may develop in the rubber. Therefore, corrosion resistant options are evaluated for each of the IFSTT components.

The most common and structurally damaging local forms of corrosion in the presence of a saltwater environment are galvanic corrosion, pitting, crevise corrosion, stress corrosion cracking, and corrosion fatigue. Severe galvanic corrosion can occur when two different metals are coupled together in a marine environment. One metal in the couple will be anodic to the other. If a galvanic couple is unavoidable an insulating material or a non-conductive coating may be used to break the electrical circuit.

Pitting is corrosion that develops in highly localized areas on a metal surface, while the remaining metal surface often is not attacked. Pitting attack is most prevelant in the immersed condition. Those metals susceptible to pitting also are found susceptible to crevice attack. Crevice corrosion occurs in joints and connections. In a crevice the oxygen supply is limited.

Stress corrosion cracking can occur when high stresses are present in a chloride solution, such as seawater. This cracking is characterized by branching transgranular cracks. The fatigue endurance limit of alloy and stainless steels is decreased in saltwater. Stainless steels, in general, have higher corrosion fatigue limits than alloy steels due to the high chromium content.

Table B shows the corrosion resistant characteristics which are considered to be the selection factors for each of the IFSTT components.

Table B. Corrosion Resistant Selection Factors

Component	General Corrosion	Pitting	Crevice Corrosion	Stress Corrosion Cracking	Corrosion Fatigue
Wire Mesh Coil	o	o			o
Pin	o	o			
End Connector	o	o	o	o	o
Crossmember	o	o	o		
Spacer	o				
Bolt	o	o	o	o	

o - denotes the selection factors considered for each component

Structural Requirements

The material requirements of each of the IFSTT components is unique. In the area of structural adequacy, each component requires varying degrees of strength, wear resistance, toughness, and fatigue strength. The structural requirements for each of the IFSTT components is discussed below.

Wire Mesh Coil

The chief structural requirement of the wire mesh coil is metal-on-metal wear resistance. The wire mesh coils of the early T-139 test tracks were found to erode as the track flexed causing relative motion between the wire mesh coils and the pins. The erosion problem was not pronounced on the final T-139 test track. Tensile strength was found to be critical in the absence of wear. Tensile tests were performed to determine the ultimate static tensile strength of the T-139 track wire coils. Tensile tests of the first three T-139 wire coils showed that the wire coil breaking strength was 18,000 pounds. In the absence of wear these coils performed adequately. The fourth and final T-139 wire coils had a breaking strength of 23,000 pounds. The strength increase was a result of the heat treatment required to obtain a high hardness wear surface.

Pin

Again, as with the wire mesh coils, the chief structural concern is metal-on-metal wear resistance. The T-139 track pin, a high carbon alloy steel, is provided good wear resistance when properly heat treated. The final T-139 test conducted at Aberdeen Proving Ground showed minimal pin wear after 1148 mile of vehicle operation. This type wear resistance is required of the IFSTT pin material.

End Connector

The structural requirements of the end connector material is strength and impact toughness. The bosses located on the male end connector are the most critically loaded area of the component. The bosses sustain a high tensile loading due to bolt preload. Additionally, these bosses are required to transmit intermittent shear loads due to static and dynamic track tension thereby requiring fatigue strength.

The major deficiency noted in the final T-139 track was the structural integrity of the male and connector in the area of the base of the bosses. This structural problem was attributed to improper casting techniques rather than being design related. The strength of the basic design was proven adequate in prior field tests.

The selection of the heat treat for the candidate material should provide good ductility and impact resistance while maintaining a high level of strength as the secondary requirement.

Crossmember

The crossmember material of the IFSTT is required to be wear resistant with a high level of bending strength. Three areas of the crossmember are of concern with regard to wear resistance. Metal-on-metal wear resistance is required at the sprocket interface and at the roadwheel center guide. Abrasive wear resistance is required on the grouser surface. Bending strength is necessary to enable the crossmember to bend roadwheel loads without permanent deformation.

Spacer

The spacer is not a primary structural component. The function of the spacer is to prevent the wire mesh from collapsing, thereby providing the track with lateral stiffness.

Bolt

The bolts are required to provide a good structural attachment between the end connector and the crossmember. The bolt is loaded primarily in tension due to the torque requirements.

Table C shows a summary of the structural selection factors for each of the IFSTT components.

Table C. Structural Adequacy Selection Factors

Component	Strength	Wear Resistance	Toughness	Fatigue Strength
Wire Mesh Coil	o	o	o	o
Pin		o		
End Connector	o		o	o
Crossmember	o	o		
Spacer				
Bolt	o			

o - denotes the selection factors considered for each component.

Corrosion Resistant Material Options

Potential candidates for use on the IFSTT are listed in Table D. The materials were analyzed in order to compare the corrosion, structural, fabricability, and cost selection factors relative to the baseline material. Table D provides a comparison of the selection factor characteristics for each component of the IFSTT. Each of the materials is ranked into the following categories for each of the selection factors under consideration.

4 - Highly Acceptable

3 - Acceptable

2 - Moderately Acceptable

1 - Marginally Acceptable

Primary Corrosion Resistant Material Selection

The primary corrosion resistant material has been selected for each of the IFSTT components. The primary material candidates are listed in Table E. The corrosion and structural properties of the material candidates have been carefully compared to the T-139 track materials. The properties of both the T-139 and the primary corrosion resistant material candidates are presented in Table F thorugh K for each track component. It can be seen that these materials should reasonably duplicate the structural performance of the T-139 materials while providing superior saltwater environment corrosion resistance.

Table E. Primary Corrosion Resistant Material Option for the IFSTT

Component	Material
Wire Mesh Coil	Nitronic 60
Pin	440 C
End Connector	15-5 PH
Crossmember	15-5 PH
Spacer	5086-H32
Bolt	A286

Table F. Properties of Wire Link Coil Material

Material	T-139 AISI 6150	Primary Candidate Nitronic 60
Condition or Heat Treat	Rc 40	ASM A580 30% C.D.
Corrosion Properties		
general corrosion	poor	>type 304
pitting resistance	poor	good
corrosion fatigue	stainless superior to alloy steels	
Structural Properties		
Ultimate tensile strength, F_{TU} (ksi)	185	161
Yield strength, F_{TY} (ksi)	175	132
Hardness, R_c	40	34
Wear Resistance	excellent	good
Impact Strength, (ft-lb)	--	50, charpy
Ductility		
elongation, e (%)	13	26
reduction in area, RA (%)	46	62
Fatigue strength @ 10^8 cycles (ksi)		
Smooth		55

Table G. Properties of the Pin Materials

Material	T-139 AISI 8640	Primary Candidate AISI 440C
Condition or Heat Treat	R_C 55-60	R_C 55-60
Corrosion Properties		
general corrosion	poor	fair
pitting resistance	poor	fair
Structural Properties		
Ultimate tensile strength, F_{TU} (ksi)	280	285
Yield strength, F_{TY} (ksi)	250	275
Hardness, R_C	55-60	55-60
Wear Resistance	excellent	excellent

Table H. Properties of the End Connector Casting Materials

Material	T-139 AISI 4330	Primary Candidate 15-5 PH
Condition or Heat Treat	R_C 36-40	H1050
Corrosion Properties		
general corrosion	poor	fair
pitting resistance	poor	fair
crevice corrosion	poor	fair
stress corrosion cracking		
air, K_{IC} (ksi/sq. in.)	80	120
sea water, K_{ISCC} (ksi/sq. in.)	60	96
corrosion fatigue, strength @ 10^8 cycles (ksi)		
smooth	15 est.	50
notched	5 est.	30
Structural Properties		
ultimate tensile strength, F_{TU} (ksi)	165	150
yield strength, F_{TY} (ksi)	145	140
hardness, R_C	36-40	34-41
impact strength, Izod (ft-lb)	35	26
ductility		
elongation, e (%)	12	8
reduction in area, RA (%)	30	19
fatigue, strength @ 10^8 cycles (ksi)		
smooth	82.5	84
notched	--	48

Table I. Material Properties of the Crossmember Casting Materials

Material	T-139 AISI 4330	Primary Candidate 15-5 PH
Condition of Heat Treat	R_C 37-41	H 1050
Corrosion Properties		
general corrosion	poor	fair
pitting resistance	poor	fair
crevice corrosion	poor	fair
Structural Properties		
ultimate tensile strength, F_{TU} (ksi)	170	150
yield strength, F_{TY} (ksi)	150	140
hardness, R_C	37-41	34-41
wear resistance	good	fair
impact strength, Izod (ft-lb)	32	26
ductility		
elongation, e (%)	11	8
reduction in area, RA (%)		

Table J. Properties of the Spacer Materials

Material	T-139 2024	Primary Candidate 5086
Condition or Heat Treat	T3	H32
Corrosion Properties		
general corrosion	poor	good
Structural Properties		
ultimate tensile strength, F_{TU} (ksi)	70	42
yield strength, F_{TY} (ksi)	50	30
Hardness, Brinell	120	--

Table K. Properties of the Bolt Material

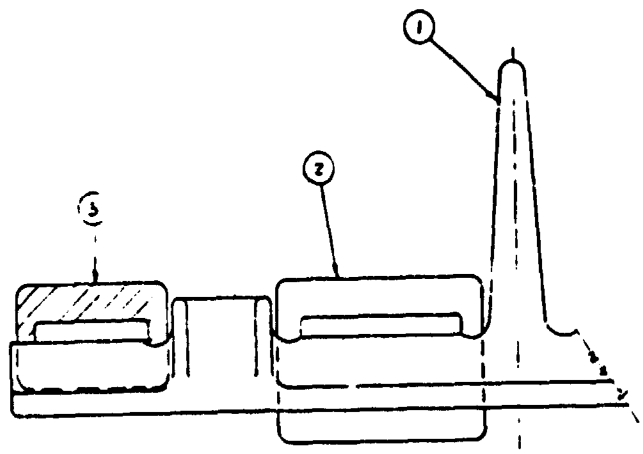
Material	T-139 Grade 8, Alloy Steel	Primary Candidate A286
Condition or Heat Treat	-	-
Corrosion Properties		
general corrosion	poor	fair
crevice corrosion	poor	fair
stress corrosion cracking	poor	fair
Structural Properties		
ultimate tensile strength, F_{TU} (ksi)	150	140
yield strength, F_{TY} (ksi)	130	--

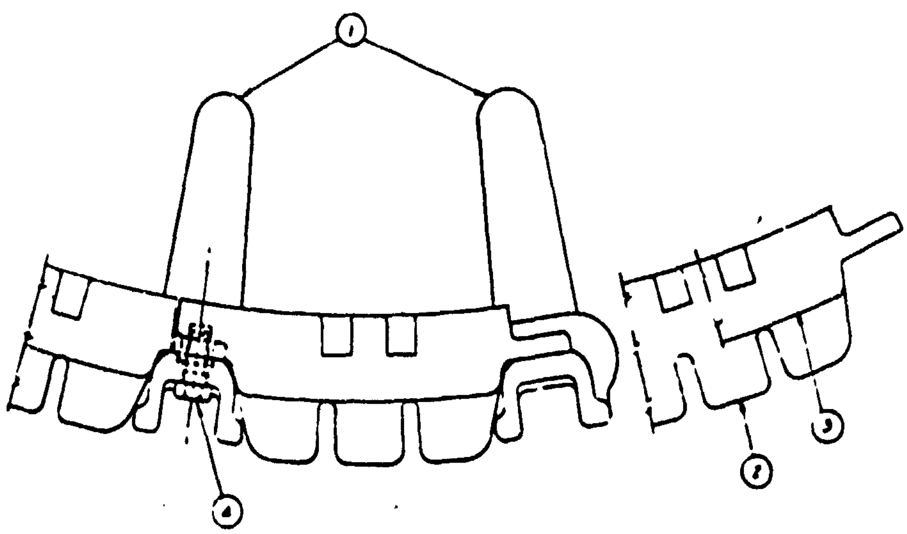
Appendix C

Physical Description

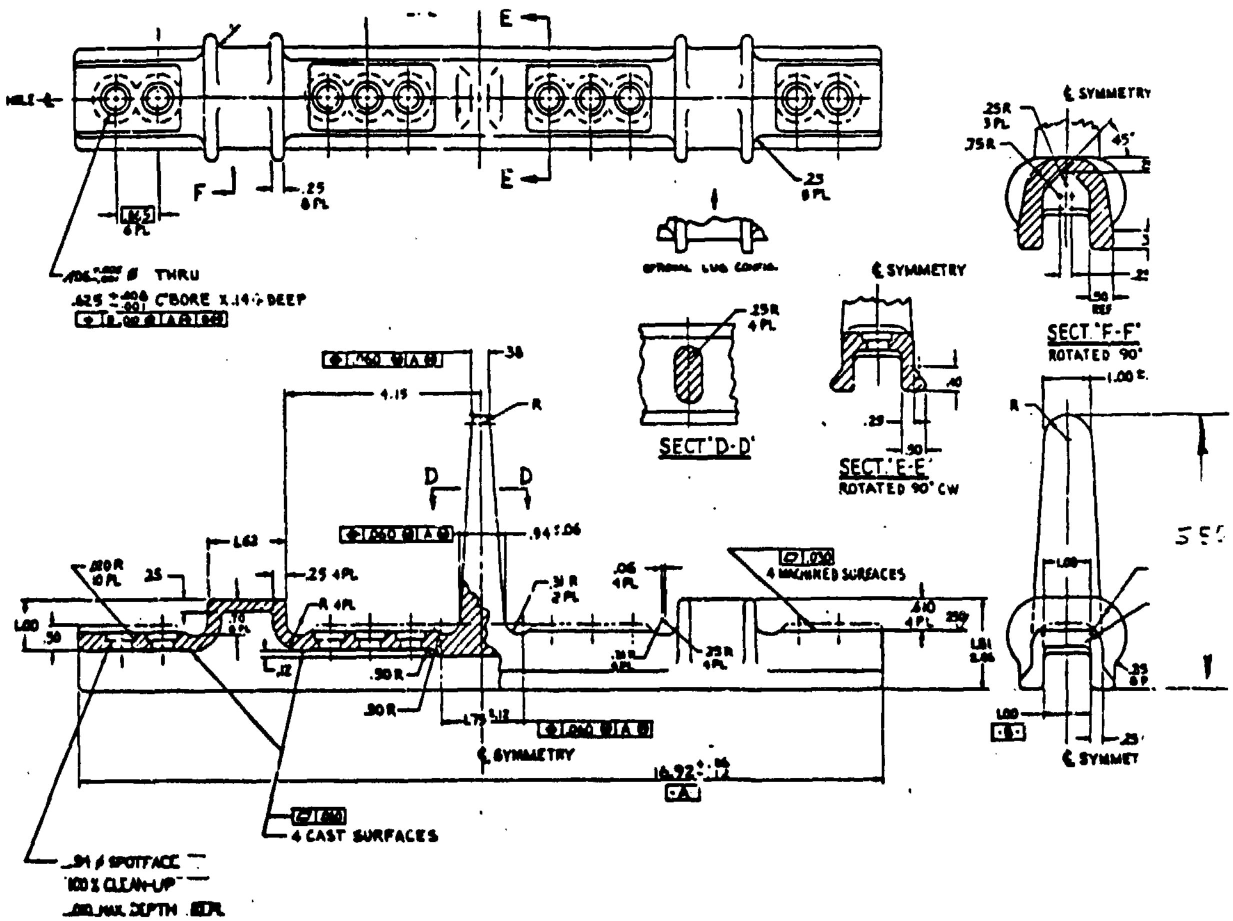
The wire link band track is composed of four basic parts. The illustration below shows the four parts which make up the track assembly. These parts are:

Item No.	Description	Quantity Req. per Pitch
1	Crossmember	1
2	Inner Track Block	2
3	Outer Track Block	2
4	Hex Head Bolts	10





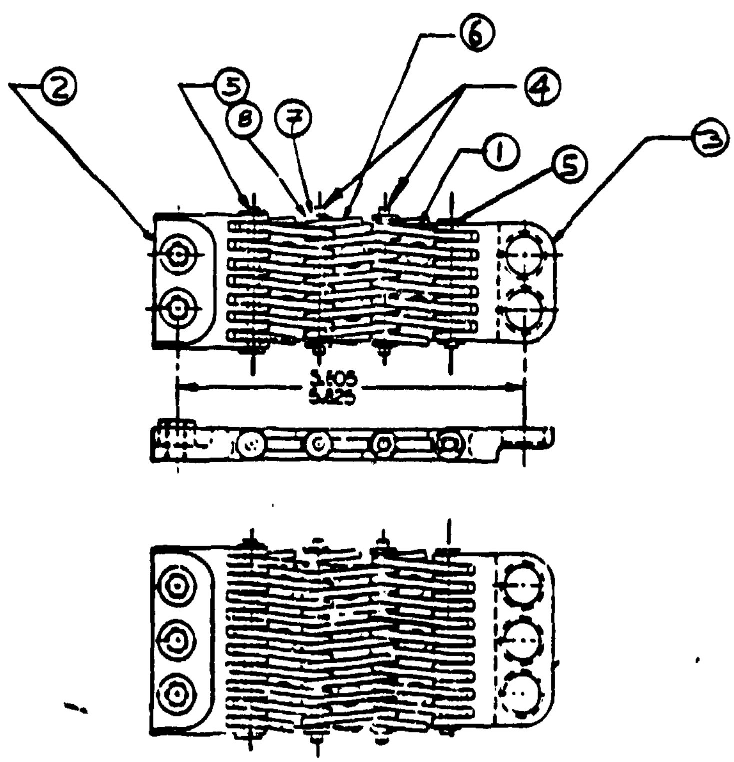
The track is driven by two sprockets which engage the crossmember at the two driving lugs. The driving lugs are located between the inner and outer track blocks on each side of the assembly. The center guided, which is located in the center of the crossmember, is used to guide the track on roadwheels.



The inner and outer track blocks are connected end to end to form continuous bands. The roadwheels ride on the inner track bands. Hex head bolts connect the track band to the crossmember.

Within each rubber molded track block are several metal components. These are:

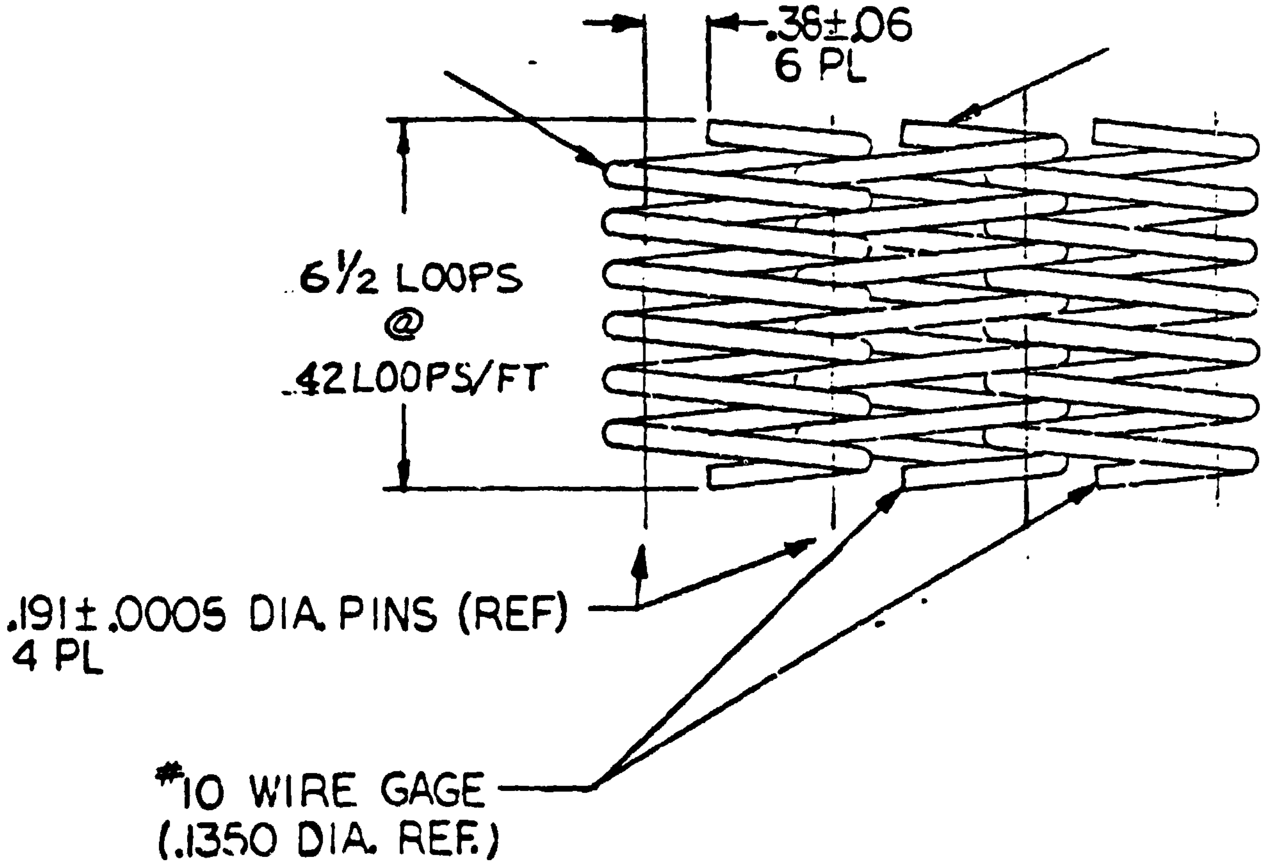
Item	Description	Quantity per Block
1	Wire mesh	3 links
2	Male end connectors	1
3	Female end connectors	1
4	Wire mesh pin	2
5	End connector pin	2
6	Spacer	3
7	Snap rings	4
8	Washer	2



Analysis Discussion

The structural capacity of the wire link track is compared to the design criteria. To do this the tensile capacity of the inner and outer track blocks are determined. The tensile capcity of the track assembly is assumed to be the sum of the two inner and outer track blocks. The total tensile capacity then can be compared to the design criteria ultimate tensile capacity of 64,000 lbs to find the margin of safety. The friction connection between the end connector is also analyzed to determine if slippage can occur. The center guide strength is also determined. The bending strength under a bridging type load and the bending strength of the center guide due to a side load are compared to the impact force on the crossmember, Pv, of 10,600 lbs and the lateral load, PL of 7,000 lbs.

Wire Mesh



The wire link track uses two of the above wire sets and two wider sets consisting of 9 1/2 loops.

Estimate the static capacity of the wire assuming the following materials:

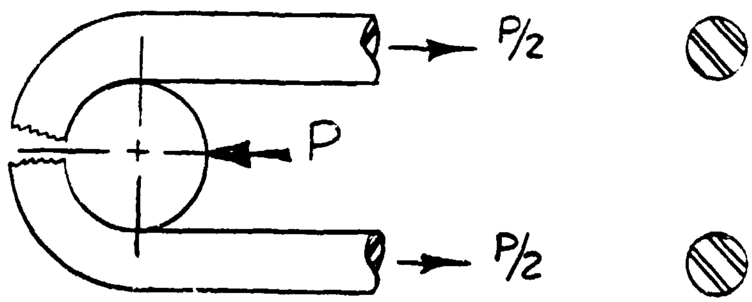
AISI 6150 H.T. to 150 Ksi
AISI 6150 H.T. to 185 Ksi
Nitronic 60 C.D. 30%

The 6150 wire was used on the T139 track. The early T139 track wire was heat treated to 150 Ksi and the last T139 wire was heat treated to 180 Ksi for the purpose of increased wear resistance. The current track was Nitronic 60 stainless steel.

Pull tests were conducted on the T139 track blocks. The new wire breaking strength of the 6 loop wire mesh used on the T139 program was:

Material	Pult (6 1/2 Loops), lbs
6150 HT to 150 Ksi	18,000
6150 HT to 180 Ksi	23,000

The tensile capcity of the wire around the pin is effected by a stress concentration factor. The equation for determining the stress in the wire is calculated as follows:



$$P_{TU} = NK_T \ (2\pi/4 \ D_w^2) \ F_{TU}$$

where:

P_{TU} = ultimate tensile capacity

N = number of wire loop

K_T = stress concentration factor and distribution factor

D_W = diameter of wire

F_{TV} = ultimate tensile strength of material

Using the test data from the T139 track the appropriate stress concentration and distribution factor can be determined as:

$$KT = \frac{P_{TU}}{N \ (\pi/2 \ Dw^2) \ F_{TU}}$$

For the 6150 wire heat treated to 150 ksi

$$K_T = \frac{18000}{6 \ (\pi/2 \ (.135)^2) \ (150000)}$$

$$= .699$$

For the 6150 wire heat treated to 180 ksi

$$K_T = \frac{23000}{6 \ (\pi/2 \ (.135)^2) \ (180000)}$$

$$= .744$$

Use .74 for K_T for new wire since the 150 ksi wire may have had notches and score marks.

The nitronic tensile strength in the 30% C.D. condition is:

$$F_{TU} = 161 \text{ ksi}$$

Then the tensile capacity of the 6 and 9 loop wire mesh is then

$$P_{TU} = NKt\,(\pi/2\ Dw^2)\ F_{TU}$$

For 6 loops

$$P_{TU} = 6 \times .744\ (\pi/2\ .135^2)\ 161000$$

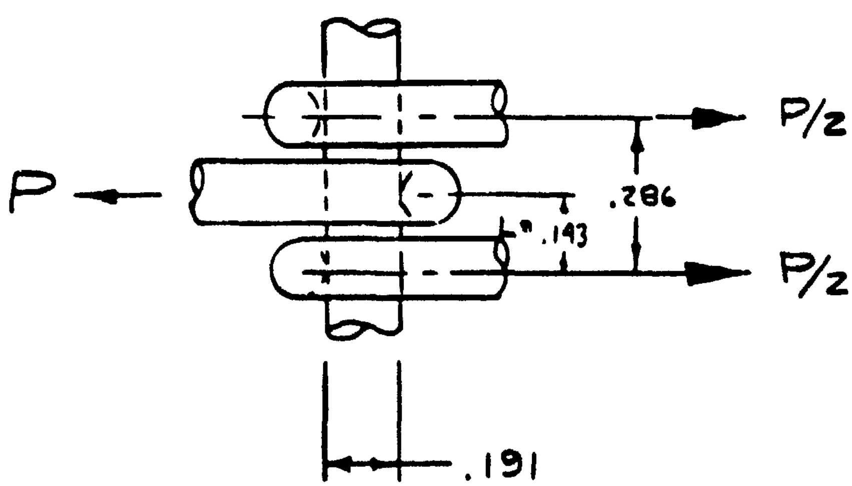
$$= 20575 \text{ lbs}$$

For 9 loops

$$P_{TU} = 9 \times .744\ (\pi/2\ .135^2)\ 161000$$

$$= 30860 \text{ lbs}$$

<u>Pins, End Connector and Mesh</u>



Find the allowable load, using the above dimensions, on the pin. Calculate both the shear stress and the bending stress. The pin material properties are:

Material of pin - 440C Rc 55-60

$$F_{TU} = 285 \text{ ksi}$$

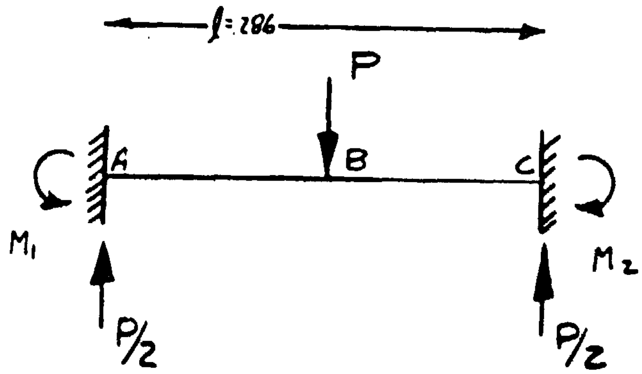
$$F_{SU} = .577 \times 285 = 164.4 \text{ ksi (von Mises-Hencky)}$$

Allowable Load in Shear

$$P_{ALL} = F_{SU} \times 2 \times \pi/4\ D_p^{\ 2}$$
$$= 164.4 \times 2 \times \pi/4\ (.191)^2$$
$$= 9421 \text{ lbs}$$

Allowable Load in Bending

Assumption - pin can be treated as a beam problem with fixed supports and center LOA



$$M_{MAX} = \frac{Pl}{8} = \frac{P \times .286}{8} = .03575\ P$$

$$I = \frac{D_p^{\ 4}}{64} = \frac{(.191)^4}{64} = 6.53 \times 10^{-5} \text{ in}^4$$

$$C = DP/2 = .191/2 = 0.0955 \text{ in}$$

$$F_{BU} = \frac{Mc}{I} = \frac{0.03575\ P \times 0.0955}{6.53 \times 10^{-5}}$$

$$F_{BU} = 52.283\ P$$

$$F_{TU} = 285{,}000 \text{ ksi}$$

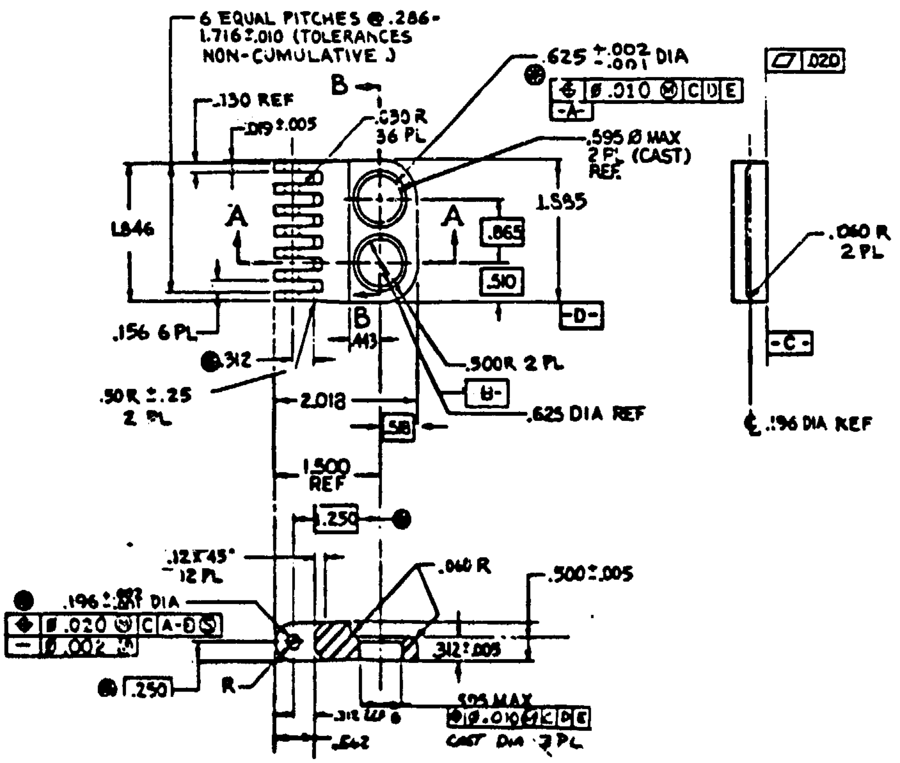
$$P_{all} = \frac{F_{TU}}{52.283} = \frac{235,000}{52.283}$$

$$= 5451 \text{ lbs}$$

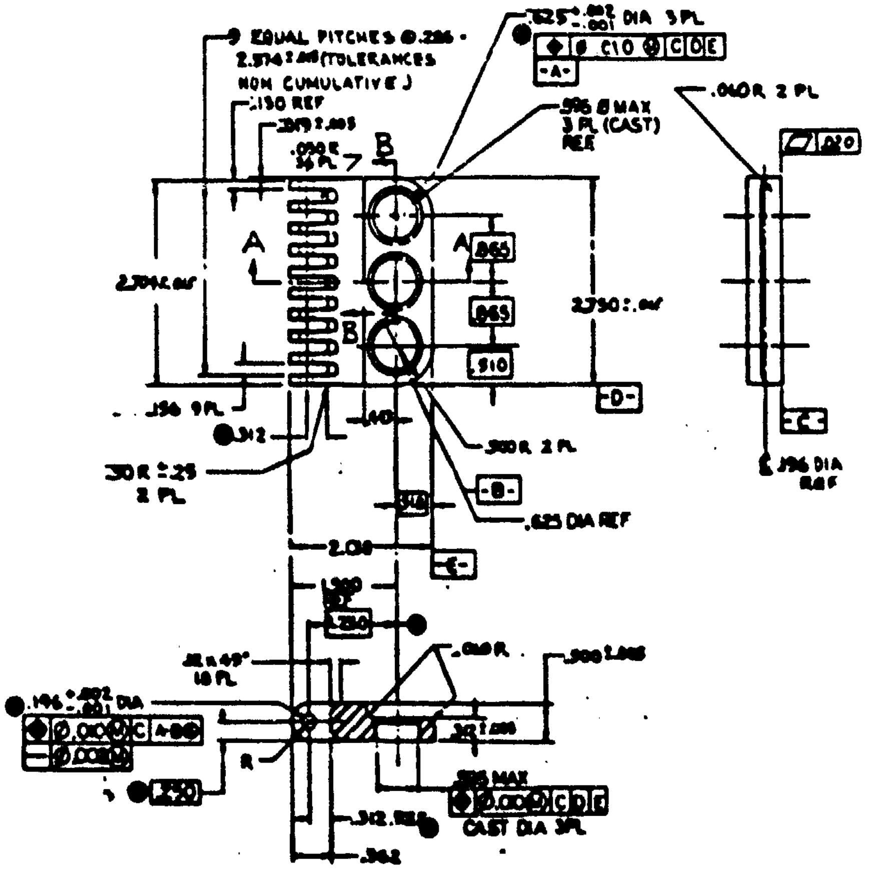
Therefore, the total load carrying capacity of the inner and outer track blocks based on pin strength:

For 6 Loops 6 x 5451 = 32706 lbs
For 9 Loops 9 x 5451 = 49059 lbs

Female End Connectors



OUTTER CONNECTOR

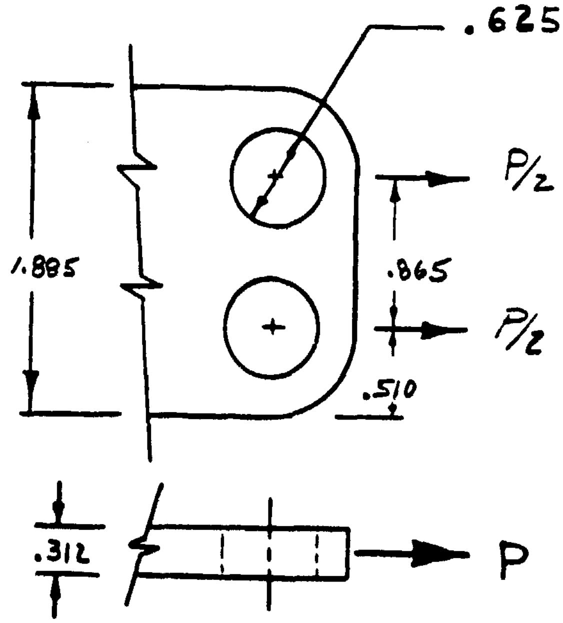


INNER CONNECTOR

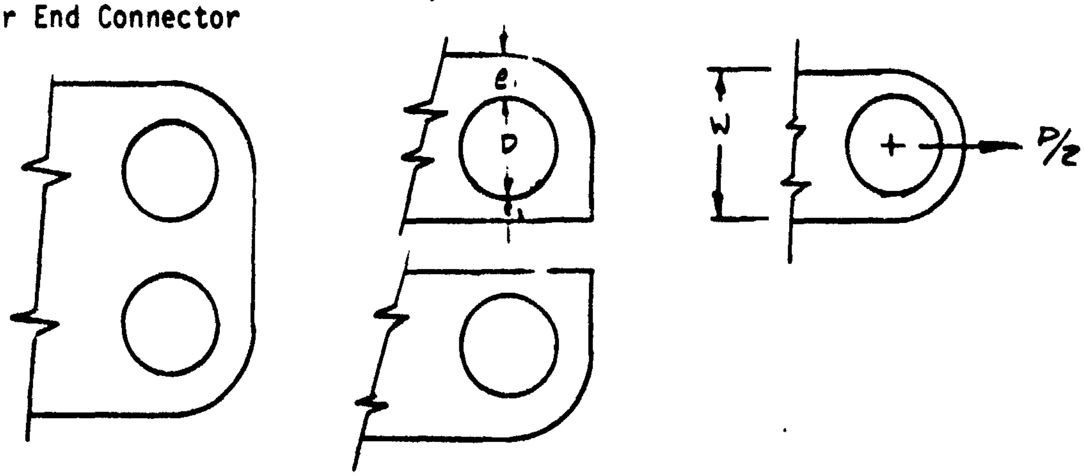
Evaluate the tensile capacity of the female end connectors. Two areas are of principle concern when under tension. These are the large and small hole sides.

Large Hole Side

The method used for calculating the allowable load is identical for the inner and outer connectors since the "equivalent lug" method is chosen. This is a conservative method and should yield reliable results.



Outer End Connector



Actual lug

Each half takes equal load

Since lug is eccentrically loaded the thinnest section limits the strength. Use the method in the Astronautic Structures Manual, Vol. 1

$$P/2 = Ke\ Kt\ Ftu\ At$$

$$P = 2\ ke\ kt\ Ftu\ At$$

where: $Ke = \dfrac{e_1 + e_2 + 2D}{2e_2 + 2D}$ $e_1 = .1975$ $D = .625$
$e_2 = .120$

$$= \frac{.1975 + .120 + 2\ (.625)}{2(.120) + 2\ (.625)}$$

$k_c = 1.052$

k_c (from autro. str. man.)

$W/D = .865/.625 = 1.38$

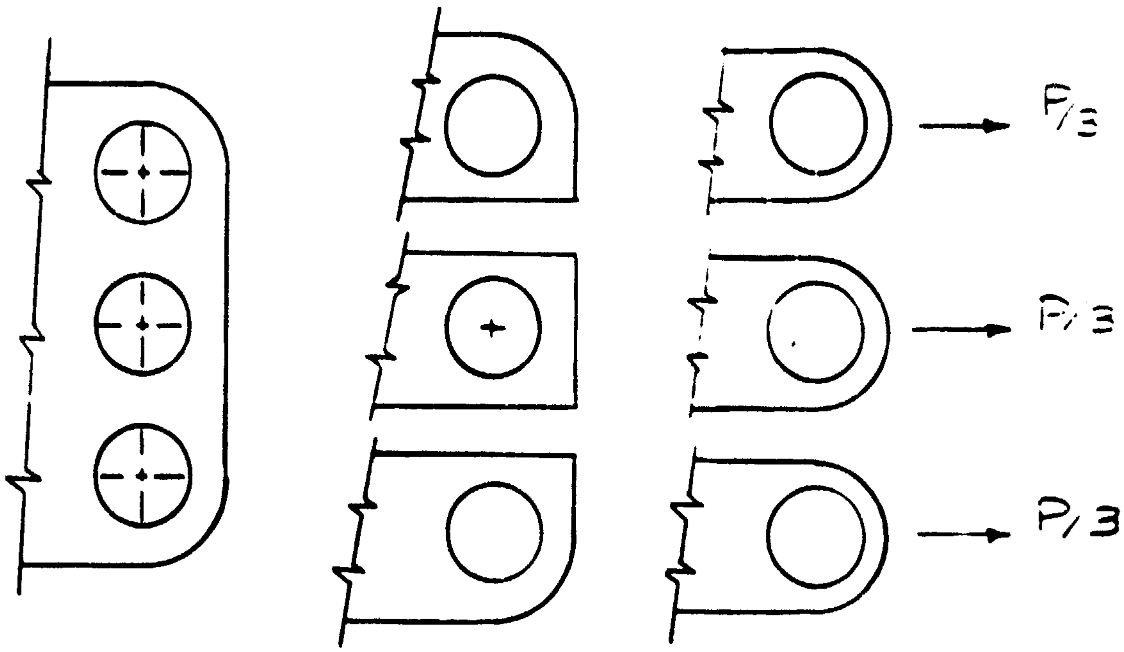
$K_2 = 0.98 \times 1.0$

$A_t = 2te_2 = 2\ (.312)\ (.120) = .0749\ in^2$

$P = 2\ (1.052)\ (1.00)\ (150000)\ (.0749)$

$= 23638$ lbs

Inner End Connector



Actual lug	Load divides equally	Outer holes are eccentrically loaded like the outer end connector. However, the inner is not eccentrically loaded and has the least tensile area.

$$P = 3 \text{ Ke Kt } F_{tu} A_t$$

where:

Kc = 1.0 center lug is not eccentric

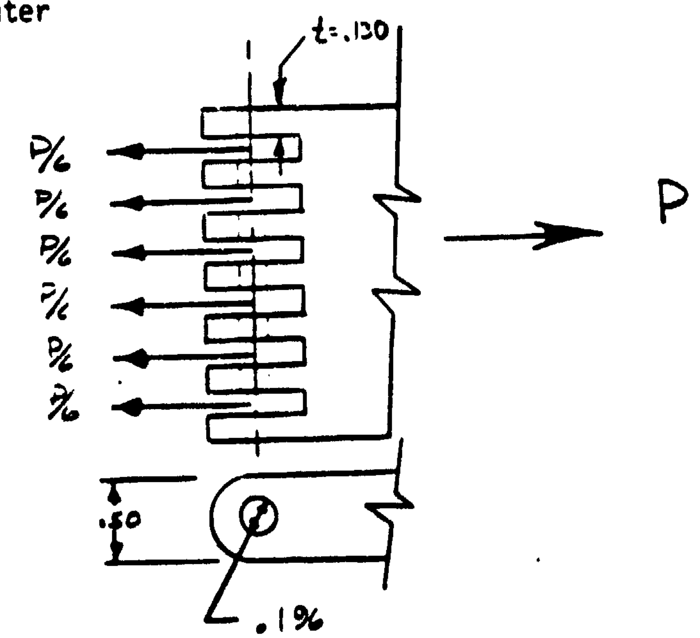
k_t = 1.0

A_t = 2 (.312) (.120) = .0749 in^2

P = 3 (1.0) (1.0) (150000) (.0749)

= 33705 lbs

Female end connector
Small hole side, outer



$P = K_t F_{TU} A_t$

K_t (from astonautic structures manual)

W/D = .5/.196 = 2.55

K_t = 0.94

A_t = 6 x (W-D) (t) assume 6 hold load since end receive 1/2 the load as middle

A_t = 6 x (.5 - .196) (.130)

.2371 in^2

P = (0.94) (150000) (.2371)

= 33,430 lbs

Female end connector
Small hole side, inner

Using the same method for the inner as used for the outer:

K_t = 0.94

A_t = 9 (W-D) (t)

= .3557

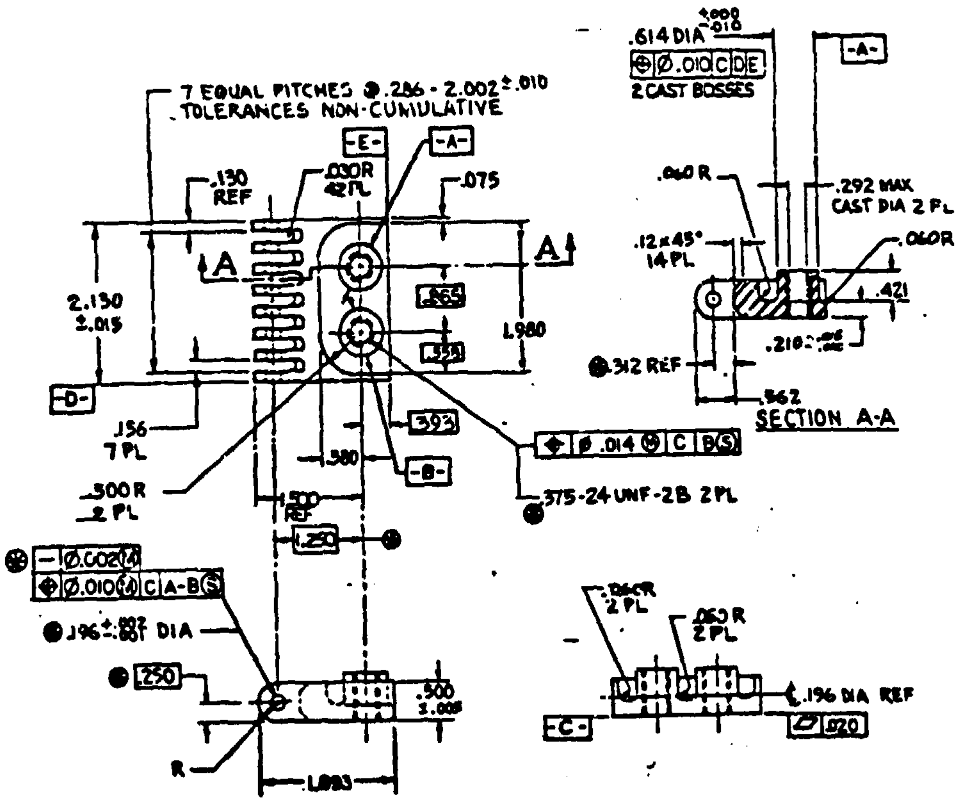
P = (0.94) (150000) (.3557)

= 50,153.7 lbs

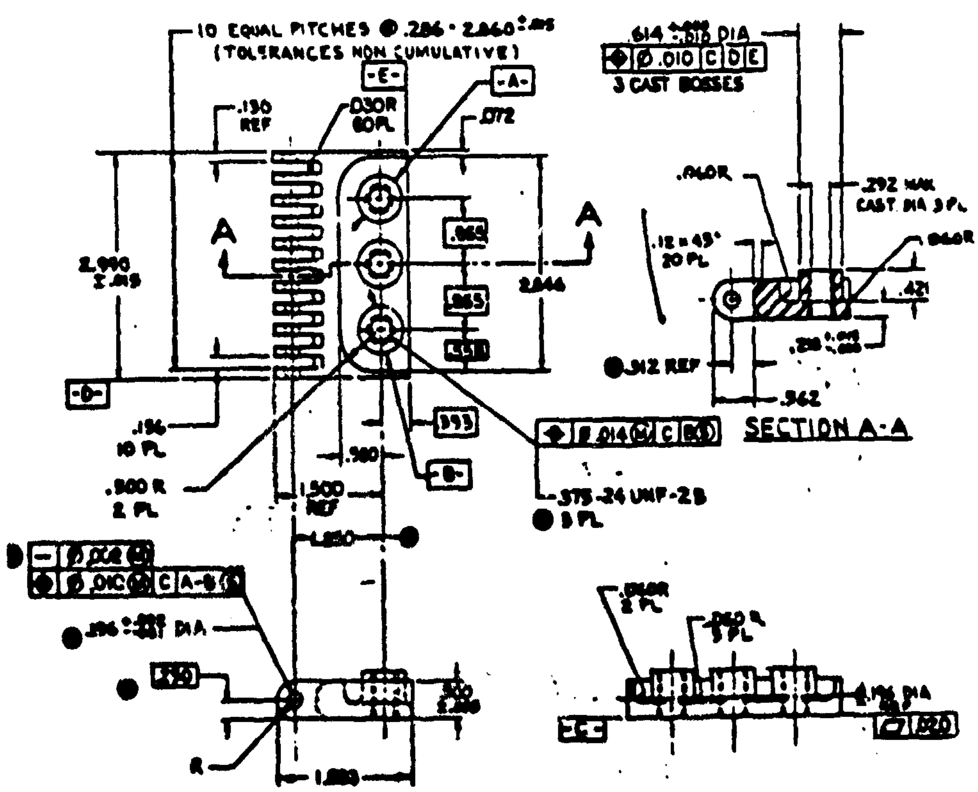
Female End Connector Summary

	Tensile Capacity (Limited by large holes)
Outer	23638
Inner	33705

Male End Connectors

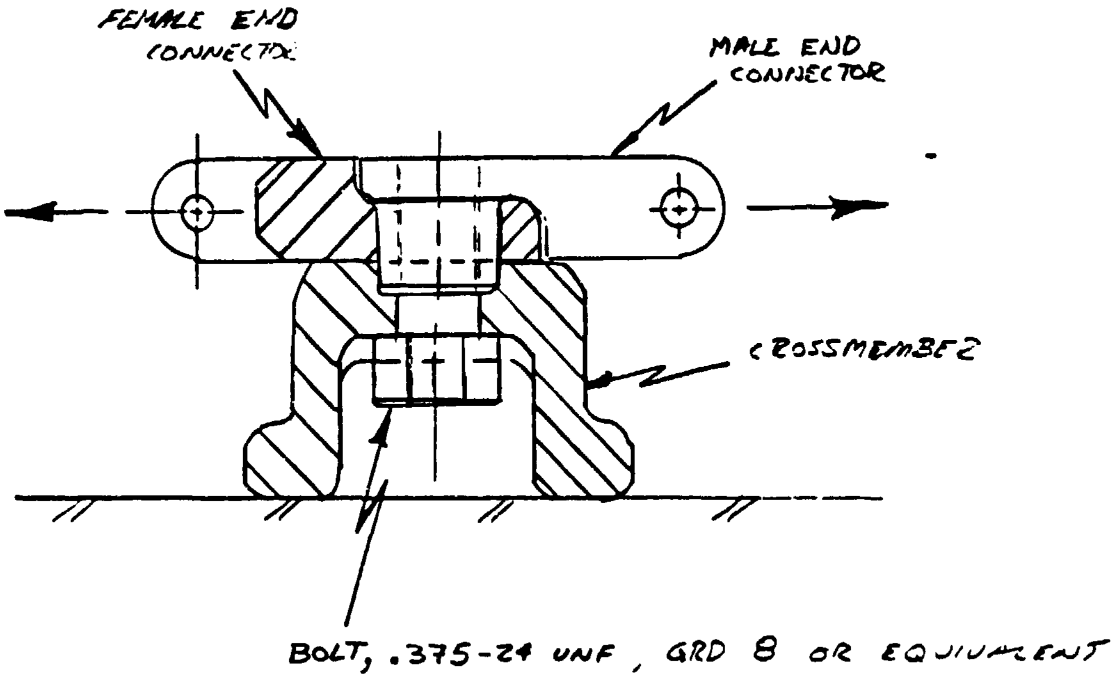


OUTTER CONNECTOR



INNER CONNECTOR

The tensile capacity of the small holes has been established in the female connector analysis. The male connectors have more load carrying tang than the female connectors and are therefore slightly stronger. The primary area of structural concern is the male bosses on the connectors. The shear and binding stresses are considered. The bolt tension will be considered.



Tension in bolt at required preload

Recommended torque = 60 ft-lbs

$$T = 0.20\ PL\ d$$

$$PL = \frac{T}{0.20xd} = \frac{12 \times 60\ [\text{in-lb}]}{0.20 \times 3/8\ [\text{in}]}$$

$$PL = 9600\ \text{lbs}$$

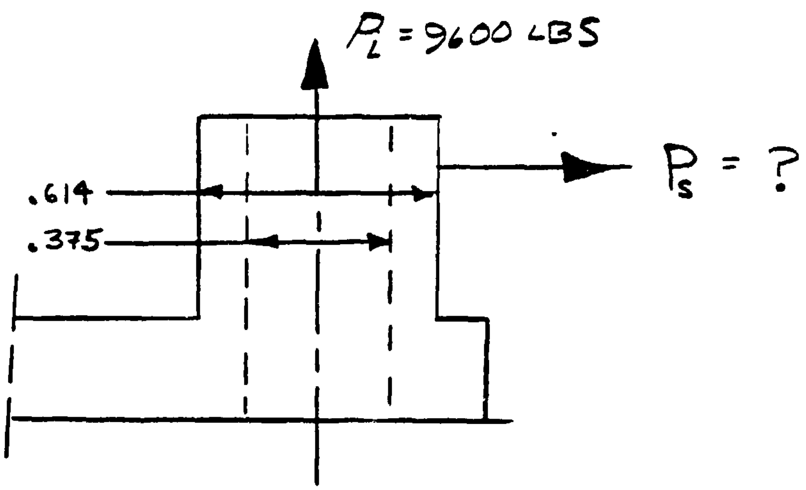
Determine the tension required to slide the end connector relative to each other with the bolt preload applied. Assume a non-greasy surface with a coefficient of friction of 0.78.

PL/Bolt = 9600 lbs

$$P_T = .78\ (9600) = 7488\ \text{lbs}$$

This load must be overcome before the shear and/or bending load can be applied. To be conservative, however, this friction will be neglected.

Allowable load due to shear and bolt preload



The shear stress and the tensile stress should be combined to find the allowable P. Using Mohr's circle the formula for principle stress is:

$$f_{tmax} = f_t + \quad (ft/2)^2 + fs^2$$

$$f_{tmax} = Fut$$

$$Fut = ft/2 + (ft/2)^2 + fs^2$$

$$Fs = \frac{Ps}{As} \qquad\qquad As = \frac{\pi}{4}((.614)^2 - (.375)^2)$$

$$= 5.3866\ Ps$$

$$FT = \frac{PL}{AT} = 51724PSI$$

$$FUT = \frac{51724}{2} + \sqrt{\left(\frac{51724}{2}\right)^2 + (5.3866\ PS)^2}$$

$$124137.8^2 = 6.688 \times 10^8 + (5.3866\ Ps)^2$$

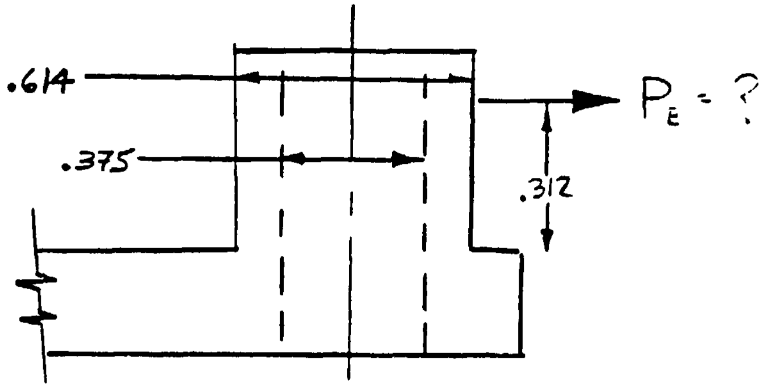
$P_s = 22540$ lbs

Total load per boss is then

$P/B = 7488 + 22540 = 30028$ lbs

Allowable load due to bending and bolt preload

$$f_B = \frac{Mc}{I}$$



$M = P_B \times .312$

$C = .614/2 = .307$

$I = \ /64\ (.614^4 - .375^4) = .0060$

$$f_B = \frac{.312\ P_B\ (.307)}{.0060}$$

$$= 15.94\ P_B$$

$f_T = 51724$ psi

$F_{TU} = f_B + f_T$

$150000 = 15.97\ P_B + 51724$

$$P_B = \frac{150000 - 51725}{8.257}$$

$$= 6{,}162$$

Male End Connector Summary

	Tensile Capacity (pounds)
Outer	12,324
Inner	18,484

Tensile Capacity of Line Assembly

Part Number	Nomenclature	Failure Mech	Tensile Capacity (lbs)
40001-50	Line Assy, Out.		
	Wire Mesh	Ultimate Tension	20575
	Pins	Bending	32706
	Female End Conn.	Tensile	23638
	Male End Conn.	Bending in Bosses	23804
			12324
40001-60	Link Assy, Inn.		
	Wire Mesh	Ultimate Tension	30860
	Pins	Bending	49059
	Female End Conn.	Tensile	33705
	Male End Conn.	Bending in Bosses	18484
			30860

Track Assembly Tensile Capacity

$$P_{UT} = 2\ (12324 + 18484)$$

$$= 61616 \text{ lbs}$$

From Design Criteria

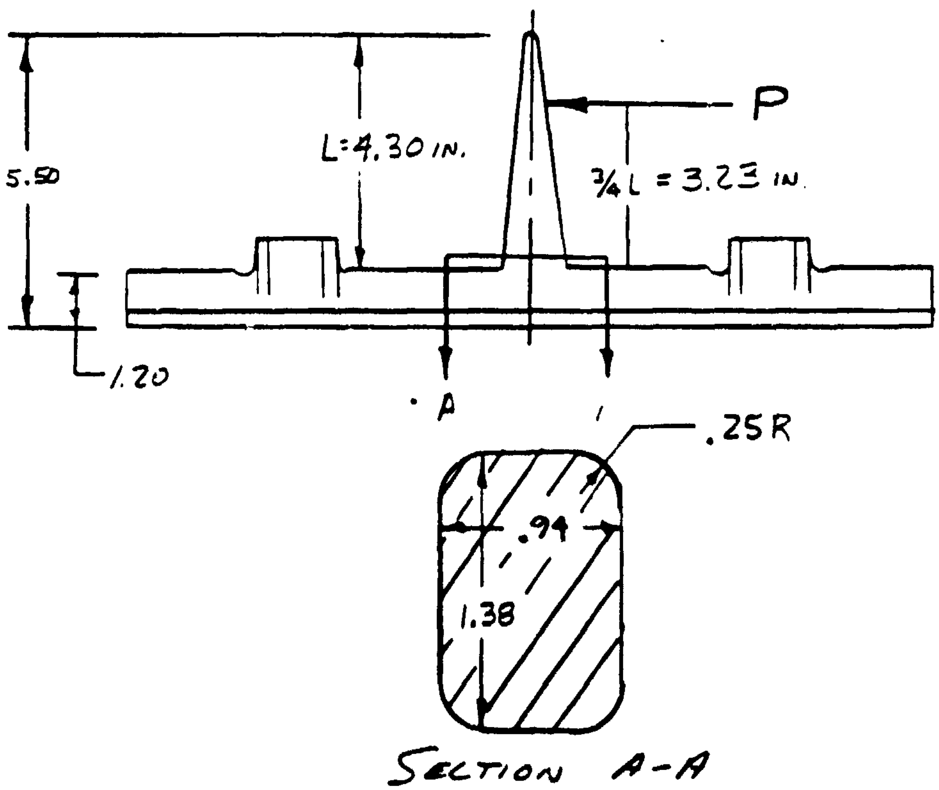
$$P_T = 64,000$$

$$Ms = \frac{61616}{64000} - 1 = 0.0373$$

Crossmember Analysis

Center Guide Lateral Capacity

From design criteria the load on the center guide is taken perpendicular to the spike at a distance of 3/4 of the total center guide height.



$$f_b = \frac{Mc}{I} \qquad F_{TU} = 150000 \text{ ksi}$$

$$M = P \times 3.23 = 3.23\ P$$

$$C = .94/2 = .47 \text{ in}$$

$$FTU = \frac{LPc}{I} \qquad P = \frac{Ftu\ I}{L\ C}$$

$$P = \frac{150000 \times 0.0955}{3.23 \times .47} = 9436.1 \text{ lbs}$$

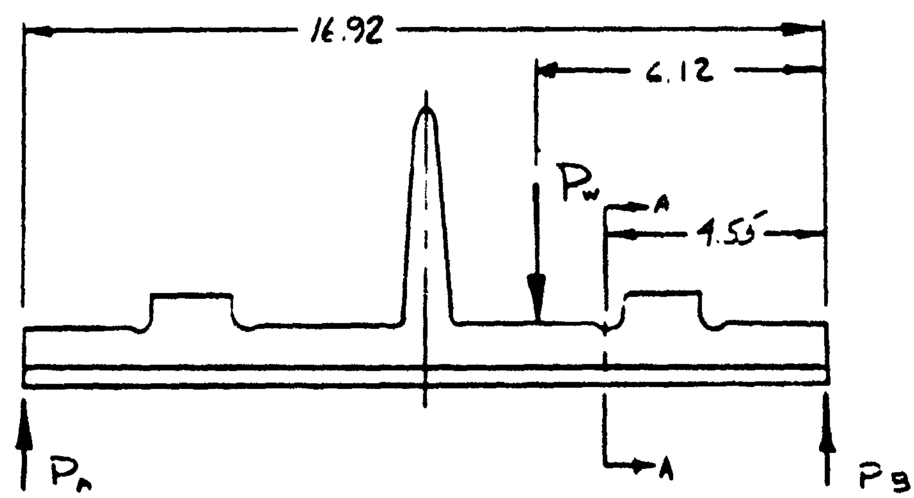
From design criteria P_L = 7000 lbs

$$M.S. = \frac{9436.1}{7000} - 1$$

$$= 0.348$$

Center Guide Bending Capacity

Assume worst ase bridging loading where the crossmember is supported by the ends and the wheel load is applied at the center of one of the bands.



$S\ F_y = 0$ $\qquad P_A + P_B = P_W$

$$P_B = P_W - P_A$$

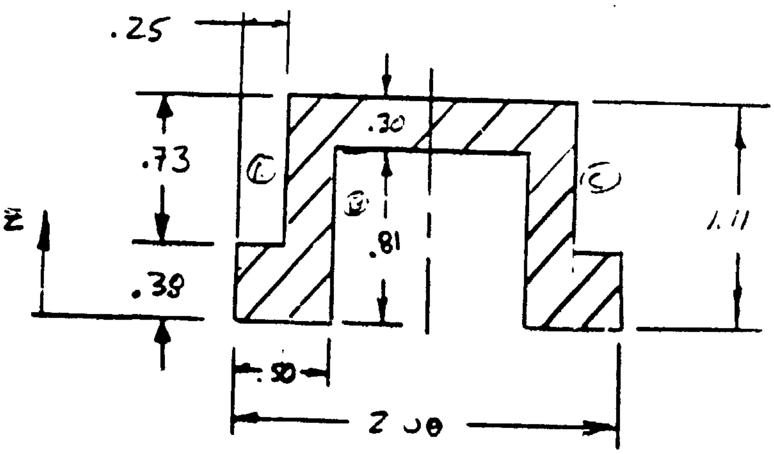
$$P_A = \frac{Pw\ (6.12)}{16.92} = 0.317\ PW$$

Bending at A-A

Moment

$$M_{AA} = P_A (16.92 - 4.55)$$
$$= .3617 \ Pw (16.92 - 4.55)$$
$$= 4.474 \ Pw$$

Section Properties at A-A



Vertical C.G. Location

Item	Area In^2	$\bar{Z}$ in	$A\bar{z}$ in^3
	2.22	.555	-0.1360
A	-.1825	.745	-0.1360
B	-.81	.405	-0.3781
C	-.1825	.745	-0.1360
	A = 1.045		$A\bar{z}$ = .6319

$$\bar{Z} = \frac{A\bar{z}}{A} = .6097 \text{ in}$$

Area Moment of Inertia

Item	Area (in^2)	Z - z (in)	$A(Z-Z)^2$ (in)	Ix in^4
	2.22	.0497	.00548	0.2279
A	-.1825	.1403	-.00359	-0.00810
B	-.81	.1997	-.0323	-0.0443
C	-.1825	.1403	-.00359	-0.00810

$Ad^2 = -0.034 \qquad I = 0.1674$

$$I = Ad^2 + I$$

$$= -0.034 + 0.1674$$

$$= 0.1334 \text{ in}^4$$

$$C = \bar{Z} = .6047 \text{ in}$$

$$f_b = \frac{Mc}{I} \qquad f_{ALL} = F_{UT}$$

$$F_{UT} = \frac{4.474 \; Pw \; c}{I}$$

Solving for Pw

$$Pw = \frac{F_{UT} \; I}{4.474 \; c}$$

$$= \frac{150000 \times 0.1334}{4.474 \; (.6047)}$$

$$= 7396 \text{ lbs}$$

From Design Criteria

$$F_v = 10{,}600 \text{ lbs}$$

$$MS = \frac{7396}{10600} - 1$$

$$= -0.302$$

Crossmember has a negative margin of safety under worst case loading condition.

Appendix D

Wire Link Track Weight analysis - 17" Wide

Comparison to:
T130E1
XT-150
M70
T138
T139 (15")

Track Component Weights

	Weight, lbs	
Component	T-139	17-inch Band Track
Deep Tread Section	2.08	2.80
No-Tread Section	1.66	1.66
Cross Members	6.97	7.46
Bolts	0.31 (eight each)	0.388 (ten each)

1 & 2 - see calculations for calculations which support each estimate

Item 1

Width of T-139 deep tread section width = 2.56 in.

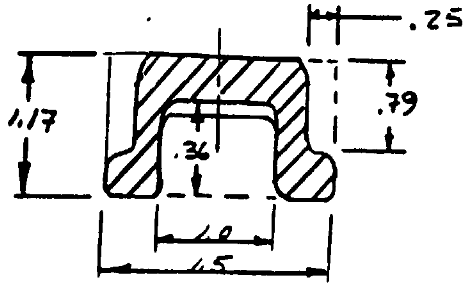
Width of 17 inch band track deep tread section width = 3.44 in.

$$\frac{3.44 - 2.56}{2.56} = .344$$

Weight of 17 inch band track deep tread section

2.08 [lbs] x 1.344 = 2.80 lbs

Item 2



$$Area = 1.5 \times 1.17 - 2\ (.25)\ (.79) - (1.0)\ (.36) = 1.0\ in^2$$

$$Volume = L \times A = 1.73 \times 1.0 = 1.73$$

$$W_c = e \times V = .283 \times 1.73 = .490\ \#$$

Track	Pitch Length in.	Weight Per Pitch lbs	Number Req. M113 ATR	Weight Installed M113	ATR
T-130	6	21.0	136	2667	2858
XT-150	6	23.5	136	2985	3196
T-139	5.8	14.76	138	1934	2037
17 in. Band	5.8	16.77	138	2197	2314

Weight Savings Summary

	Weight Savings, LBS
M113	
T-130 vs XT150	-318
T-130 vs T-139	733
T-130 vs 17 in band	470
ATR	
T-130 vs XT150	-340
T-130 vs T-139	819
T-130 vs 17 in band	542

Added Component Weights

Additional Components Required

- o Extended Hub Bolt
- o Hub Spacer
- o Idler Extension
- o Road Wheel Extension
- o Sprocket Tires
- o Sprocket Spacer

Extended Bolts

Bolt Extension

One inch extension required on each road wheel hub and idler hub.

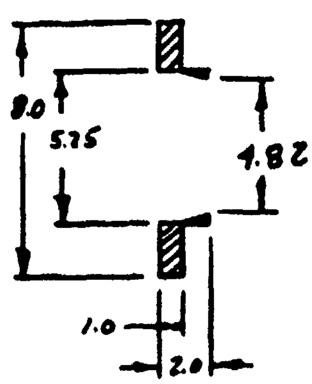
8 bolts/hub
10 road wheel hubs
2 idler hubs
.625 in. bolt diameter
bolt material - steel

$$W_{Bolts} = (\rho \times \Delta L \times \pi/4\ (D)^2)\ (N_{RWH} + N_{IH})\ (N_{B/H})$$

$$= (.282 \times 1 \times\ \ /4(.625)^2)\ (10 + 2)\ (8)$$

$$= 8.31 \text{ lbs}$$

Hub Spacer



$$V = \pi/4\ (8^2 - 5.25^2) + .1065\ (\ \ (5.0))$$

$$= 30.29 \text{ in}^3$$

$$W_c = e\ \ V = .100 \times 30.29 = 3.029$$

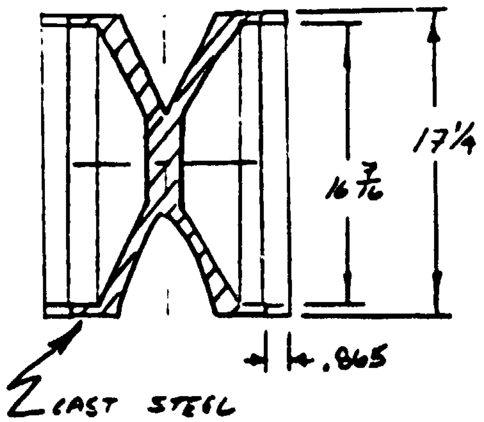
$N_{REQ} = 12$

$W_t = Wt/hub \times N_{REQ}$

$= 3.029 \times 12$

$= 36.35$ lbs

Idler Extension



4 extension rings required

$V/ring = \pi/4(L)\ (D_o^2 - D_i^2)$

$= \pi/4\ (.865)(17.25^2 - 16.44^2)$

$= 18.54\ in^3$

$W_t/RING = .282\ (18.54)$

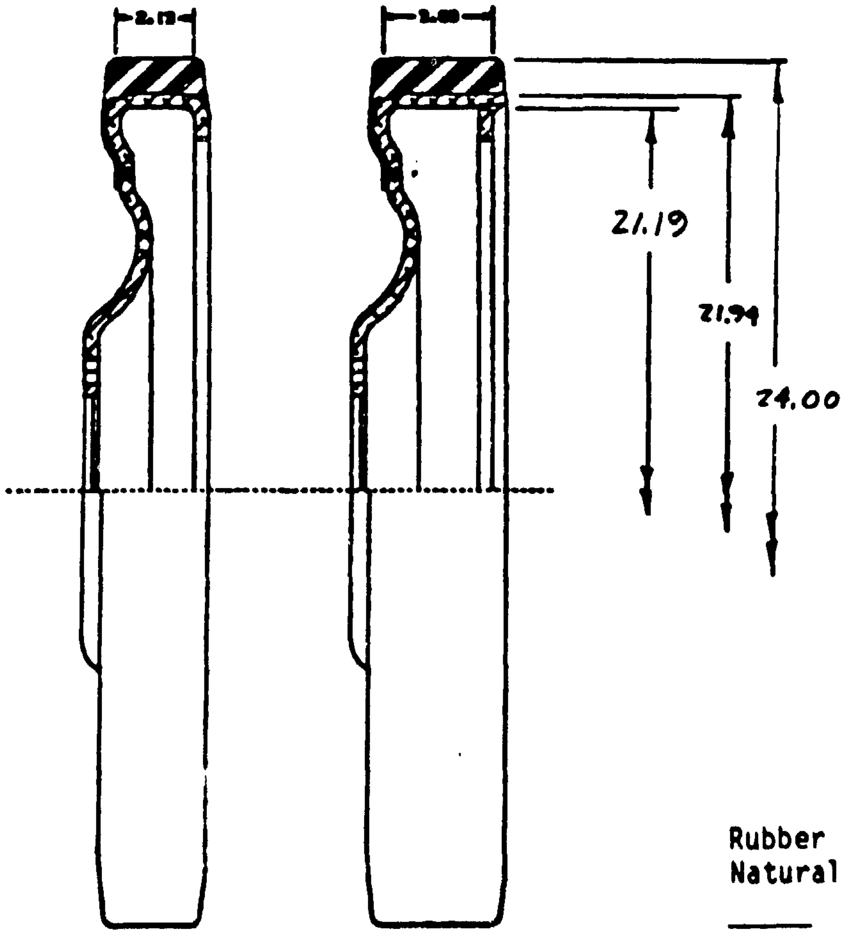
$= 5.23$ Ks

$W_t = 4\ W_t/RING$

$= 4\ (5.23)$

$= 20.9$ lbs

Road Wheel Extensions



Existing M113 Road Wheel

Modified M113 Road Wheel

Rubber	Specific gravity
Natural	.96 - .92
	.91 - 1.34

Water = 62.4 lbs/ft^3

$$e_{RUBBER} = \frac{1.5 \times 62.4}{1728} = 0.054$$

The road wheel modification increases the aluminum and the rubber at the rim. An increased wheel width is .875 inches.

$$\text{Volume/wheel (AL)} = \pi/4(21.94^2 - 21.19^2) \times .875 = 25.41 \text{ in}^3$$

$$\text{Volume/wheel (rubber)} = \pi/4(24^2 - 21.94^2) \times .875 = 65.04 \text{ in}^3$$

$$W_t\text{/wheel} = P_{RUBBER}\ \text{V/WHEEL(RUB.)} + P_{AL}\ \text{V/WHEEL (AL)}$$

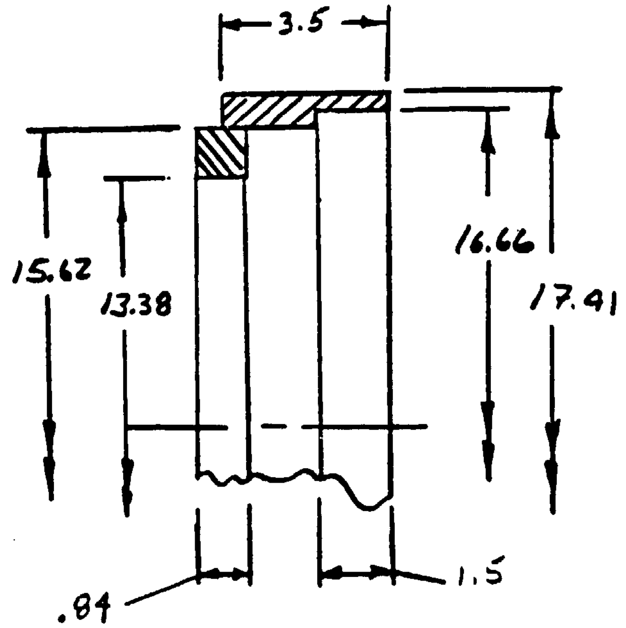
$$= 0.054 \times 65.04 + 0.1 \times 25.41$$

$$= 6.05 \text{ lbs}$$

$$W_t = 24 \times 6.05 = 145.3 \text{ lbs}$$

Sprocket Tires

Inner Tires



$$\text{Volume} = \pi/4[(15.62^2 - 13.38^2).84 + (17.41^2 - 15.62^2)3.5 - (16.66^2 - 15.62^2)\,1.5]$$

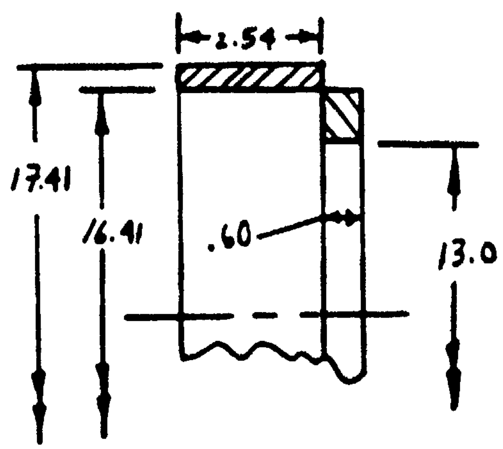
$$= 165.83 \text{ in}^3$$

$$W_t = P \times V$$

$$= .282 \times 165.83$$

$$= 46.76 \text{ lbs}$$

Outer Tires



$$\text{Volume} = \pi/4[(2.54)(17.41^2-16.41^2) + (.6)(16.41^2-13^2)]$$

$$= 114.73 \text{ in}^3$$

$$W_t = P \times V$$

$$= .282 \times 114.73$$

$$= 32.35 \text{ lbs}$$

Sprocket Tires

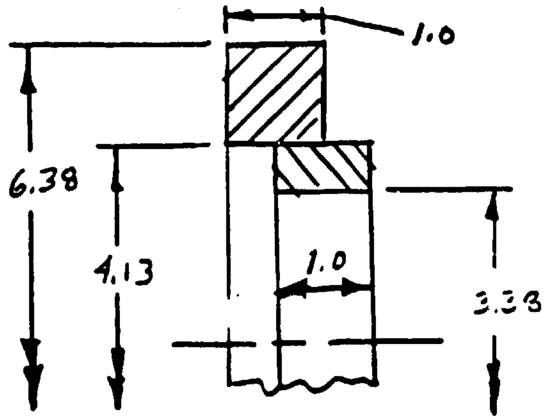
N_{inner} (REQ) = 4

N_{outer}(REQ) = 4

Weight = 4[46.76 + 32.35]

= 316.45 lbs

Sprocket Spacers



Volume = $\pi/4\ (6.38^2 - 3.38^2)$

= 23.0 in^3

Weight = .282 x 23.0

= 6.486 lbs

Weight/Vehicle = No. Req x Weight

= 2 x 6.486

= 12.97 lbs

Vehicle Modification Weight Summary

	Total Weight, LBS
Extended Hub Bolts	8.31
Hub Spacer	36.35
Idler Extension	20.90
Road Wheel Extension	145.30
Sprocket Tires	316.45
Sprocket Spacer	12.97
	540.28

Wire Link Track Laboratory Test Plan

1.0 INTRODUCTION

1.1 Overview and Test Objectives

A 17 inch wide, lightweight, improved performance band track for a 14-ton amphibious vehicle is being developed by AAI Corporation under contract to the David Taylor Naval Ship R&D Center; Contract No. N00167-82-C-0149. The track is based on the T139 track which was designed, fabricated, and tested by AAI for the U.S. Army Tank-Automotive Command under Contract No. DA-36-034-ORD-3191.

Information learned from the previous track development program has been used to improve the design. The modifications to the T139 track design are as follows:

1. Track width increased from 15 inches to 17 inches.
2. Width of inner track bands increased by .865 inches.
3. Crossmember lengthened to 17 inches.
4. Metal component materials changed for added corrosion resistance.

Component	T-139	17-Wide Band
Wire Mesh Coil	AISI 6150	Nitronic 60
Pin	AISI 8640	4406
End Connector	AISI A 4330	15-5 PH
Crossmember	AISI 4330	4330, 15-5 PH
Spacer	2024-T3	5086-H32
Bolt	Grade 8	A-286

5. Headed pins with improved snap rings are used to prevent pin migration.
6. Larger radius on bosses, larger contact area, and improved heat treat to prevent fractures of end connector.

In order to demonstrate the feasibility of the 17 inch band track design a laboratory test is required. The evaluation objectives of the laboratory test are the following:

1. Track Assembly Interface
2. Vehicular Modification Interface
3. Structural Integrity of Vehicle Modifications
4. Metal Coil/Pin Wear
5. Resistance of Molded Rubber to Cracking
6. Heat Buildup in Links
7. Effect of Variations in Track Tensioning
8. Effect of Saltwater on Track Components
9. Stainless vs Alloy Steel Crossmember Performance Comparison

The rubber compound which was used on the final T139 track tested was Standard Products natural rubber R281. This rubber performed successfully during field tests at Aberdeen Proving Ground. Therefore, the same compound which was used on the T139 track was selected for use on the 17 inch band track. However, the exact ingredients for this compound are no longer available in large quantities. Substitution can be made to arrive at a compound that closely matches the R281 used in 1964. Since the performance of the modified compound is uncertain small quantities of the original R281 compound, the modified R281 compound and a promising alternate compound R230, will be fabricated. Laboratory testing will be used to select the rubber compound to be used on the full scale vehicle test track.

The results of the laboratory testing will be included in the Monthly Progress reports and will be formally presented in the Final Technical Report data item A007.

1.2 Description of the Laboratory Test Machine

To meet the objectives listed in paragraph 1.1 a laboratory test machine has been fabricated. The test machine is a simple structure which is designed to mount both a final drive unit and an idler assembly from a M113 vehicle. Twenty-two sections of the 17 inch wide band track can be mounted around these two suspension elements. The final drive input is a hydraulic motor which is driven by an electrically driven hydraulic power unit. The power unit has the capability for a maximum oil flow of 41 GPM. This flow will allow the hydraulic motor to drive the sprocket at a speed of 544 RPM. The track tension is controlled by linking a hydraulic cylinder to the idler assembly. A "shop air over oil" pressure intensifier is used to provide hydraulic pressure from 0 to 3000 psi to the hydrualic cylinder. The maximum resulting track tension is 7400 pounds. The number of idler wheel revolutions experienced during testing will be measured with a truck tire hubodometer. To obtain the number of revolutions of the idler from the mileage reading, multiply the number of miles by 973.

1.3 General Test Procedure and Rationale

The laboratory testing of the 17 inch wide wire link track is accomplished by driving the track at one controlled speed and tension for a minimum of 7 hours per day. At night, when the machine is not rotating, the tension will be maintained. During this shut-down period a select portion of track will be exposed to saltwater. The specific data concerning the testing and evaluation details will be obtained as specified in paragraph 2.0.

There are three goals for the selection of test machine operating speed and tension. Firstly, the speed and tension should be related to the actual vehicle operating conditions. This will insure that the severity of the test is of the correct order of magnitude. Secondly, the operating point should be related to the previously obtained test data from the T139 development program. This permits data correlation between old and new test data. The final objective is to provide a simple testing procedure that is easily controlled to maximize data reliability. For this reason, only one specific speed and three tension settings have been selected. This permits the machine to operate without requiring a full time technician thereby reducing the cost of test operation.

The primary consideration in selecting the type of saltwater environment used on the test machine is the desire for a comparison of track performance with and without saltwater. For this reason only a select predetermined portion of track will be subjected to saltwater. This will be accomplished at night, when the machine is not rotating. During this period, saltwater will be pumped into the base of the test machine such that the bottom strand of track blocks are immersed in the water while the upper strand is unaffected. During this time the track tension will be maintained.

1.3.1 Track Speed Selection

Since the test machine will be operated at only one speed careful attention is given to the speed selected. A high rate of speed is desired to provide both accelerated flexing of the rubber molding and the pin to wire interface. Flexing of the rubber allows the evaluation of heat buildup. Flexing of pins and wire influences the wear of these components. Therefore, the number of flexures per unit time is the primary speed control parameter. To relate the test machine to an actual vehicle speed the following relationship is used:

$$\frac{\text{Flexures}_{\text{(Test Machine)}}}{\text{Hour}} = \frac{\text{Flexures}_{\text{(Vehicle)}}}{\text{Hour}}$$

It has been conservatively assumed that 7 flexures occur per revolution of the track on an M113 vehicle. That is, one flexure is considered to occur at each of the five roadwheel stations, at the rear idler, and at the drive sprocket. In one track revolution the M113 vehicle moves 31.42 feet. Then:

7 flexures = 31.42 feet traveled
or
1 flexure = 8.50×10^{-4} miles traveled

On the test machine, 2 flexures occur per track revolution. Then, 2 flexure occur in 2.157 revolutions of the sprocket wheel or:

1 flexure = 1.078 revolutions of the sprocket

It is now possible to directly relate the speed of the sprocket to an equivalent vehicle speed. The relationship is derived as follows:

$$\frac{\text{Flexures}_{\text{(Test Machine)}}}{\text{Hour}} = \frac{\text{Flexures}_{\text{(Vehicle)}}}{\text{Hour}}$$

Substituting the distance the vehicle travels per flexure yields:

$$\frac{\text{Flexures}_{\text{(Test Machine)}}}{\text{Hour}} = \frac{8.50 \times 10^{-4}\ \text{Miles}}{\text{Hour}}$$

Substituting the revolutions of the sprocket per flexure yields:

$$\frac{1.078 \text{ Revolutions of sprocket}}{\text{Hour}} = \frac{8.50 \times 10^{-4} \text{ Mile}}{\text{Hour}}$$

or

$$.0180 \text{ RPM} = 8.50 \times 10^{-4} \text{ MPH}$$

or

$$1 \text{ MPH} = 21.143 \text{ RPM}$$

Based on the relationship above, the T139 track laboratory tests were performed at an equivalent vehicle speed of 25-30 mph. This is considered a rapid cruising speed and therefore is a valid speed for evaluating heat buildup and pin/wire wear. Therefore, a speed equivalent to 26 MPH has been selected for the test machine. To obtain an equivalent speed of 26 MPH requires a sprocket speed of 530 RPM which is within the capabilities of the test setup.

Since the hubodometer mounted to the idler wheel on the test setup is calibrated to read one mile every 973 wheel revolutions, a conversion factor to determine equivalent vehicle mileage is required. Therefore, multiply the reading by 0.7569 to obtain the equivalent vehicle mileage. This factor considers the relationships between flexures and sprocket revolution together with the relative pitch diameters of sprocket and idler wheels.

1.3.2 Track Tension Selection

The purpose of applying track tension on the laboratory test track is to simulate tractive effort which primarily affects pin/wire wear. According to data obtained from the FMC Corp., the average operational track tension on the M113A1 is 4000 pounds. A 4000 pound tension translates to a 133 pound load per wire mesh coil loop. This is very close to the tension used on T139 track tests which were loaded 137.5 pounds per wire mesh coil loop. Futher, an analysis of the theoretical tractive effort with static tension considered show that a 4000 pound tension is the maximum obtainable at 26 MPH. Figure 1.3-1 shows the results of the theoretical track tension study along with the test machine capabilities. For these reasons the tension selected at the start of testing is 4000 pounds requiring 1630 psi fluid pressure in the hydraulic cylinder. After 1000 equivalent vehicle miles the track tension will be increased to 5500 pounds requiring 2241 psi fluid pressure. The machine will be run at this tension for another 1000 equivalent vehicle miles. Then for the remainder of the testing, the track tension will be increased to 7400 pounds requiring 3000 psi. It is anticipated that the machine will be run 2000 equivalent vehicle miles at the 7400 pound track tension.

1.4 Test Specimen Description and [illegible] Condition

The track components which were fabricated for the laboratory test have been inspected and have several deficiencies which are mentioned

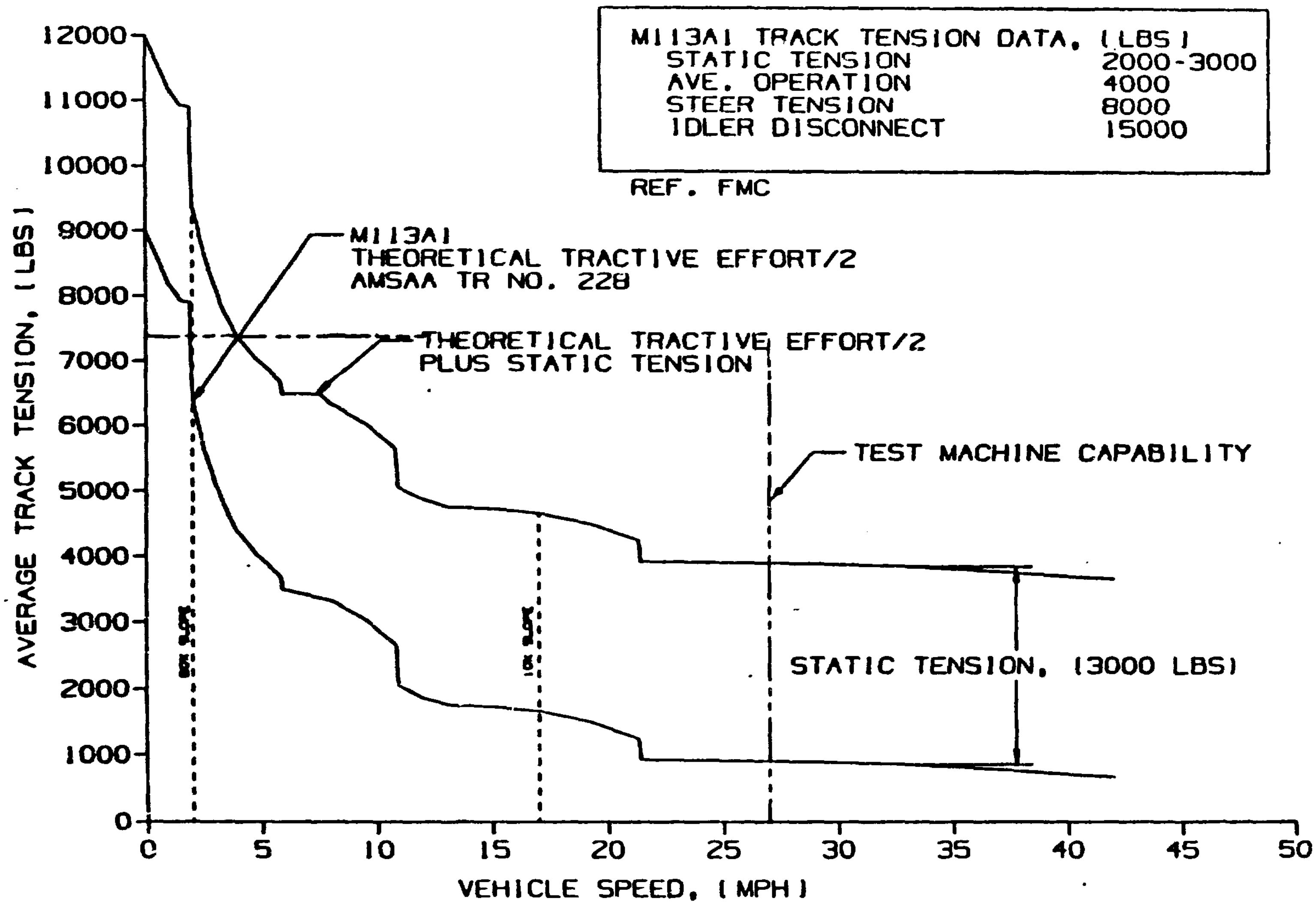


Figure 1.3-1 Track Tension Comparison

below. None of these deficiencies are anticipated to degrade the performance of any of the components. However, corrective action has been taken to insure that the components used for the full scale vehicle track do not have these deficiencies.

The wire mesh links have been formed successfully from Nitronic 60 30%CD. Several improvements involving an improved pin to wire fit are being evaluated. The improvements involve increasing the stretching load, thereby producing a more flat coil. Samples of these coils molded in blocks will be included in the test.

The end connector castings have been inspected and dimensionally approved with the exception of one area. Rejection of many parts was experienced due to overgrinding when removing the casting sprue. A grinding fixture was not used, thereby causing the part to be overground. Forty (40) unusable parts were returned to the vendor. The remedy for this problem will be to use a grinding fixture on the next quantity. Additionally, non-ferrous shot peening material will be specified to prevent iron from being impregnated into the surface of the connectors. The quantity of end connectors remaining will permit 72 inner and outer limits to be assembled for rubber molding purposes.

The spacers were too long in overall length. The length was reduced at AAI on a mill for the test machine quantity. The balance of the spacers required for the test track have been returned to the subcontractor for corrective action.

The full order, for lab and full scale test, of pins have been delivered to AAI. Many did not meet the required straightness tolerance and all pins were delivered with cracked heads. The cold formed heads cracked during forming. These cracks may lead to stress corrosion cracking. Although these heads are not load bearing, the condition is undesirable and therefore, 3500 pins were returned to the subcontractor for replacement. Enough pins were retained at AAI to permit the laboratory testing of 72 inner and outer track blocks. AAI is working with the subcontractor in order to fabricate the cold headed pins without cracked heads. Double annealed wire is being procured by the subcontractor for the replacement pins since the wire on hand is not fully annealed. Consideration is being given to modifying the heading die to improve formability. Potential alterations are a smaller head diameter, a greater head thickness and a larger radius under the pin head. Attention will be given to any modification to insure that the performance of the pins will in no way be compromised.

All parts have been physically assembled to form link assemblies. The only problem experienced was that the wire mesh twisted when fitted into the end connectors. This problem has been corrected with a simple post twisting operation.

Sample stainless crossmember castings have been received and are generally acceptable for lab test purposes. A total of 25 of these cross-members are being made with 10 carbon castings to follow for incorporation in the test.

Three natural rubber compounds will be evaluated on the laboratory test machine. These are the original Standard Products R281, a modified Standard Products R281 and a Standard Products R230 compound. Only a limited supply of the ingredients required to make the original R281 is available. Therefore, an alternate compound must be found. Substitutions can be made to arrive at a modified R281 compound that will closely match the performance of the modified R281. Since the performance of the modified R281 compound is unknown a promising alternate compound R230 will also be tested. The R230 compound is the same compound that Standard Products uses for track pin bushing materials. Standard Products will provide a detailed physical properties comparison to aid in selection of the proper track compound. Rubber molded parts have not been received so the condition of these parts will be reported in the test report.

1.5 Distribution of Track Variables on the Test Machine

The quantity and placement of the track variables will remain consistent through the duration of the track test. Each part mounted on the machine will be serialized in order to identify the variables in each one. Figure 1.5-1 shows numbers which will be assigned to each section and crossmember. The serial numbers will be stamped on the female end connectors of each track block for positive identification. Additionally, since the stamped number is not visible when the track is assembled, the number will be painted on the outer tread for visual identification. The crossmember will also be stamped on the center guide for a positive identifier. Paint will also be used for quick visual identification. The test track will be stopped at the point shown in the Figure when the saltwater is introduced in the bottom of the test fixture.

The physical variables considered in the laboratory test are:

1. Three different rubber compounds;
2. Two different crossmember materials;
3. Two types of wire mesh (standard and tight weave).

In addition to the physical variables, one installation variable will be evaluated. The direction of one type end connector will be oriented towards the direction of the track rotation for the inner and outer track band on one side of the center guide. The direction will be reversed for the other two track bands on the opposite side of the center guide.

The distribution of the track variables is shown in Table 1.5-1. The serial numbers in the table refer to Figure 1.5-1. The rationale for this arrangement is to assure that at least one test sample of each variable is positioned to provide data on sections immersed in saltwater to those not subject to saltwater immersion.

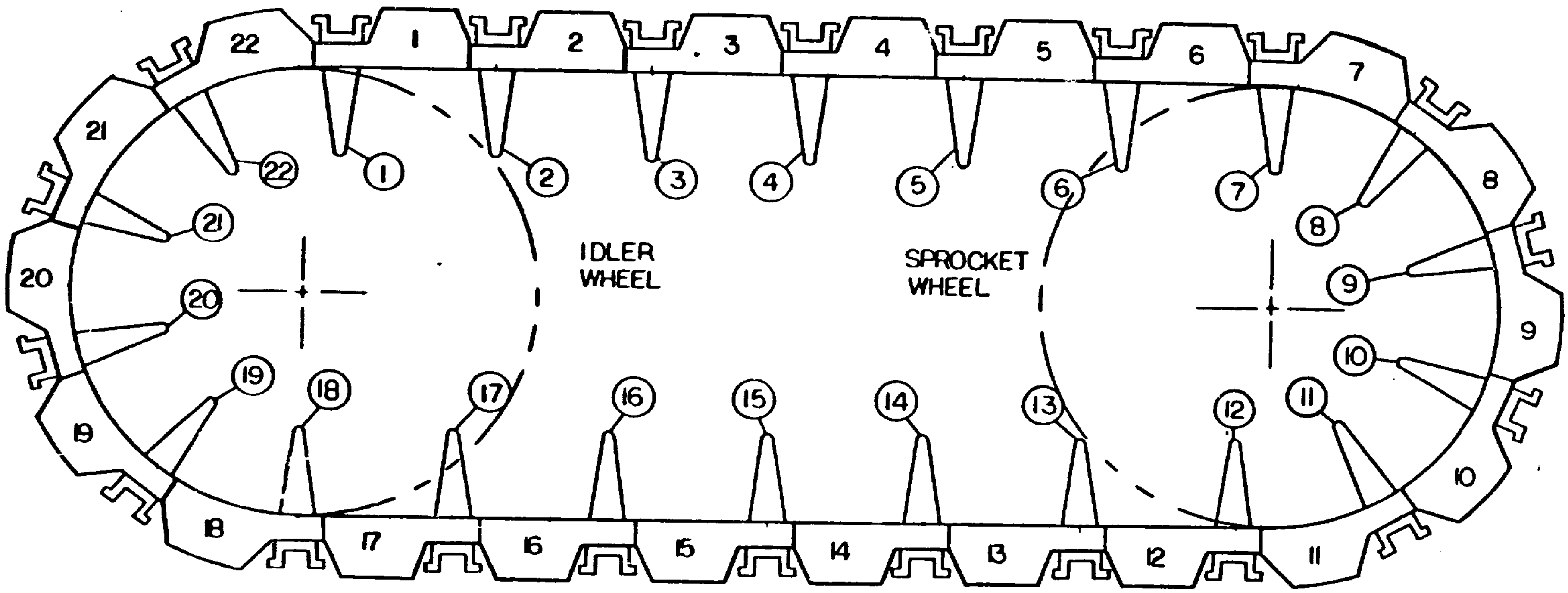


Figure 1.5-1 Test Specimen Serial Numbers

Table 1.5-1 Track Test Specimen Distribution

Serial Number	Wire	Rubber	Crossmember Material
1	TIGHT	R281	15-5PH
2	STD	Old R281	15-5PH
3	STD	Old R281	4330
4	STD	R281	15-5PH
5	STD	R281	4330
6	STD	R281	4330
7	STD	R281	4330
8	STD	R281	4330
9	STD	R281	4330
10	STD	R281	4330
11	TIGHT	R281	4330
12	TIGHT	R230	4330
13	STD	Old R281	4330
14	STD	Old R281	15-5PH
15	STD	R281	15-5PH
16	STD	R281	15-5PH
17	STD	R230	15-5PH
18	STD	R230	15-5PH
19	STD	R230	15-5PH
20	STD	R230	15-5PH
21	STD	R230	15-5PH
22	STD	R230	15-5PH

2.0 TESTING AND EVALUATION DETAIL

2.1 Track Assembly Interface

2.1.1 Objective

A proper track assembly interface is required to insure good wear characteristics. Assembly interface concerns both the relationship between each of the link assembly components and the rubber molded blocks to each other as well as to the crossmember.

2.1.2 Data Required

The critical interfaces on the link assembly which will be evaluated will be:

1. Wire mesh to end connectors
2. Wire mesh to pins
3. Spacers to wire mesh and pins
4. Pins to end connectors
5. Pins to snap ring

The final track assembly interfaces which will be evaluated will be:

1. Crossmember to rubber molding
2. Molded block to adjacent molded block
3. Bolt to crossmember and molded blocks

2.1.3 Data Acquisition Procedure

All components of the wire link track will first be reviewed by the AAI Corp. Inspection Department. This will determine if the components match the drawings. The engineer will inspect all interfaces and record the observations. Inspection tools will be used when necessary.

2.2 Track Installation Interface

2.2.1 Objective

The proper mesh of the track with the drive sprocket will insure that the crossmember will wear properly and that the track will not be thrown. Track engagement and disengagement with the sprocket are two areas of major concern.

2.2.2 Data Required

Three interface conditions occur between track and the drive sprocket. These are: sprocket driving, sprocket idling, and sprocket braking. Engagement and disengagement in these three conditions should be evaluated.

2.2.3 Data Acquisition Procedure

High speed films can be taken showing the track engagement and disengagement in the sprocket driving, sprocket idling and sprocket braking conditions. The sprocket idling condition can be evaluated with the track test machine operating at a constant speed. The sprocket driving condition will be evaluated with the sprocket accelerating the track. The braking condition will be evaluated with the sprocket decelerating the track. However, since driving and braking torques will be low, the results may not depict the actual field conditions.

2.3 Interface and Structural Integrity of Vehicle Modifications

2.3.1 Objective

The test machine uses the same suspension modification components as the actual vehicle test bed.

These are:

1. Idler/Road wheel hub spacer
2. Sprocket Wheels
3. Sprocket Tires
4. Sprocket Spacer

The fit of these components will be evaluated at installation. The structural integrity of the idler/road wheel attachment arrangement will be evaluated on the laboratory test machine. The addition of the one inch thick spacer has moved the wheels away from the wheel hub mounting flange. This displacement from the wheel hub has permitted the wheels to come away from the hub pilot diameter of (5.245/5.237) inches. Therefore, the proper location of the wheels must be maintained with the mounting bolt clamping forces. The maximum test track tension will be 7400 pounds resulting in a radial force through the wheel joint of 14800 pounds. This load exceeds the maximum anticipated road wheel impulse loads and is therefore a valid measure of the joint strength.

2.3.2 Data Requirement

A proper interface between all the vehicle modification components must be established.

The idler/road wheel hub spacer modification is of primary structural concern. Slippage of the wheel on the hub spacer will constitute failure of design. The wheel must remain on center.

2.3.3 Data Acquisition Procedure

The interface of the suspension modification components will be evaluated at the assembly of the test machine. A description of all interfaces will be recorded.

The structural integrity of the idler/road wheel hub spacer will be evaluated at the conclusion of laboratory testing. Slippage of the idler wheel on the spacer will be determined by using a dial indicator. The track will be removed and the wheel will be rotated with a dial indicator reading the variations in wheel diameter. The idler wheels are installed on the test machine such that this reading is $\pm$0.010 inches at the beginning of testing.

2.4 Metal Coil/Pin Wear

2.4.1 Objective

Wear of the wire mesh coils on the pins was one of the major factors influencing track failures of early T139 tracks. Excessive wear causes track stretch and reduces the load carrying capacity of the track. Through extensive laboratory and field tests the wear problems of T139 elements was overcome. Laboratory and field tests correlated well. Stainless steel materials have been substituted for the original T139 materials to improve the saltwater corrosion resistance. The principal factor used in the selection of a stainless steel concerned the wear resistance properties. The materials selected have a high level of wear resistance. The laboratory test machine will be used to evaluate the wear of the pins and wire. More wear will be apparent on the wire mesh coils since the wire is the softer of the two metals. This wear is expected to be most pronounced at the interface with the end connectors.

2.4.2 Data Required

Track stretch and tensile strength of the track as a function of time or test miles is required.

2.4.3 Data Acquisition Procedure

To determine track stretch, measurements of the pitch length of each of the track sections will be made at approximately 200 mile intervals with the track under tension. This data along with the mileage will be recorded in a daily log. The pitch length will be checked by measuring the distance between adjacent crossmembers. The crossmember will have reference points on top of each lug which will be used for the measurement.

Destructive testing will be used to determine the tensile strength of the track at various stages of testing. Pull testing will be done at the following equivalent mileages with the rubber intact: 0, 1000, 2000, 3000, and 4000 miles. The quantity of samples to be pulled will be dictated by the number of spares available. The following section serial numbers will be removed from the test machine at the appropriate mileages:

Mileage	Serial Numbers
0	two each, untested samples
1000	5
2000	6
3000	7
4000	1,8,11,15,16

Each block on the sections removed will be pull tested. The sections will be replaced with new track blocks which have the same wire and rubber materials as the ones removed. Replacements are not required for the sections removed at an equivalent mileage of 4000, since 4000 miles will conclude the laboratory testing.

2.5 Resistance of Molded Rubber to Cracking

2.5.1 Objective

Cracking of the molded rubber was another of the major factors which contributed to failures of the early T139 track. Cracks in the rubber allow abrasive materials to enter the wire mesh/pin interface thereby accelerating wear. Once cracks form the track life is short. The final rubber compound R281 together with the curved block design solved the cracking problem on the final T139 track test. After 1000 miles of field testing at APG no evidence of cracking could be found.

Three rubber compounds will be tested. These are:

1. R281 (same as used in 1964)
2. R281 (modified)
3. R230

The laboratory test machine data will be used to determine the proper compound for the full scale vehicle field test. The distribution of the rubber compounds on the test machine is shown in Table 1.5-1.

2.5.2 Data Required

Evidence of crack initiation and growth will be recorded in the daily log.

2.5.3 Data Acquisition Procedure

At the completion of each test day the observer will carefully inspect each track block of each section. The condition of each will be recorded.

2.6 Heat Buildup in Links

2.6.1 Objective

Heat buildup in the rubber molded links can lead to hot tearing, chunking, and blowouts. For this reason, the heat buildup in the links for each of the rubber compounds will be evaluated in order to address these problems.

2.6.2 Data Required

The temperature will be measured at several locations on selected inner and outer track blocks. Serial numbers 2, 4, and 22 will be the sections used to measure heat buildup in the old R281, R281, and R230, respectively.

Heat buildup will be measured at the start of testing to measure break-in temperatures, at 600 miles to measure temperatures under 4000 pounds track tension, at 1600 miles to measure temperatures under 5500 pounds track tension, and at 2600 miles to measure temperatures under 7400 pounds track tension.

2.6.3 Data Acquisition Procedure

A pyrometer will be inserted into the pre-drilled holes in the test specimens. The temperature in these areas will be recorded.

2.7 Effect of Variations in Track Tensioning

2.7.1 Objective

As discussed in Section 1.3.2, the track tension will be adjusted as follows:

Mileage, Miles	Track Tension, LBS
0-1000	4000
1000-2000	5500
2000-4000	7400

Pin and wire wear will be recorded as specified in Section 2.4. It is expected that the increases in track tension will impact the pin and wire wear rate. It is also recognized that the track tensions above 4000 pounds are much higher than would be realized on an M113 vehicle at the flexing speed of 26 MPH.

2.7.2 Data Required

Recording of the track stretch and growth at the higher track tensions is required. Any other observations will be recorded.

2.7.3 Data Acquisition Procedure

The track pitch length will be measured in accordance with the procedures outlined in 2.4.3.

2.8 Effect of Saltwater on Track Components

2.8.1 Objective

The effects of saltwater on the wire link track is unknown. For this reason a comparison between components exposed and not exposed to saltwater is desired. A pan located in the bottom of the test machine will be used to subject a select portion of track to saltwater each night. The serial numbers subjected to saltwater will be 10 through 19.

2.8.2 Data Required

No specific data is required for this test and evaluation. However, all other data will be affected by the saltwater.

2.8.3 Data Acquisition Procedure

The data obtained concerning wire/pin wear, rubber cracking and crossmember wear will be influenced by the saltwater exposure in track sections 10 through 19. Therefore, the data will serve as a measure of the effects of saltwater on the track component and no additional data is required.

2.9 Stainless vs Alloy Steel Crossmember Performance Comparison

2.9.1 Objective

The performance of stainless and alloy steel crossmembers will be evaluated on and off of the test machine. Track lug wear and crossmember strength is of particular interest.

The degree of lug wear is of little importance on the test machine since the driving force is small. What is important, however, is the comparison of wear performance of the stainless versus alloy steel crossmember.

2.9.2 Data Required

Crossmember lug wear and bending strength is required.

2.9.3 Data Acquisition Procedure

The crossmember lug wear will be recorded in the daily log. Photographs and micrometer readings at 0, 1000, 2000, 3000 and 4000 miles of equivalent vehicle travel will be taken. A vertical cross-section of the crossmember at the drive lug will be cut at the end of 4000 miles to compare the wear of the 4330 crossmember to the 15-5 PH crossmember. A shadograph will be used to record the profile of the lugs.

The bending strength will be evaluated through destructive testing of the crossmember. Stainless steel crossmembers S/N 1, 2, 15, 16 and the carbon steel crossmembers S/N 5, 6, 12, 13 will be tested under a bridging load in the laboratory. A load deflection curve will be obtained from this test.

3.0 Test Schedule

The test schedule based on equivalent vehicle mileage appears as Figure 3.0-1. It is estimated that at a rate of 26 mph (the equivalent vehicle testing speed) and assuming an 6 hour day, 156 miles can be run each day. Four thousand miles can therefore be reached in 26 days from the start of testing.

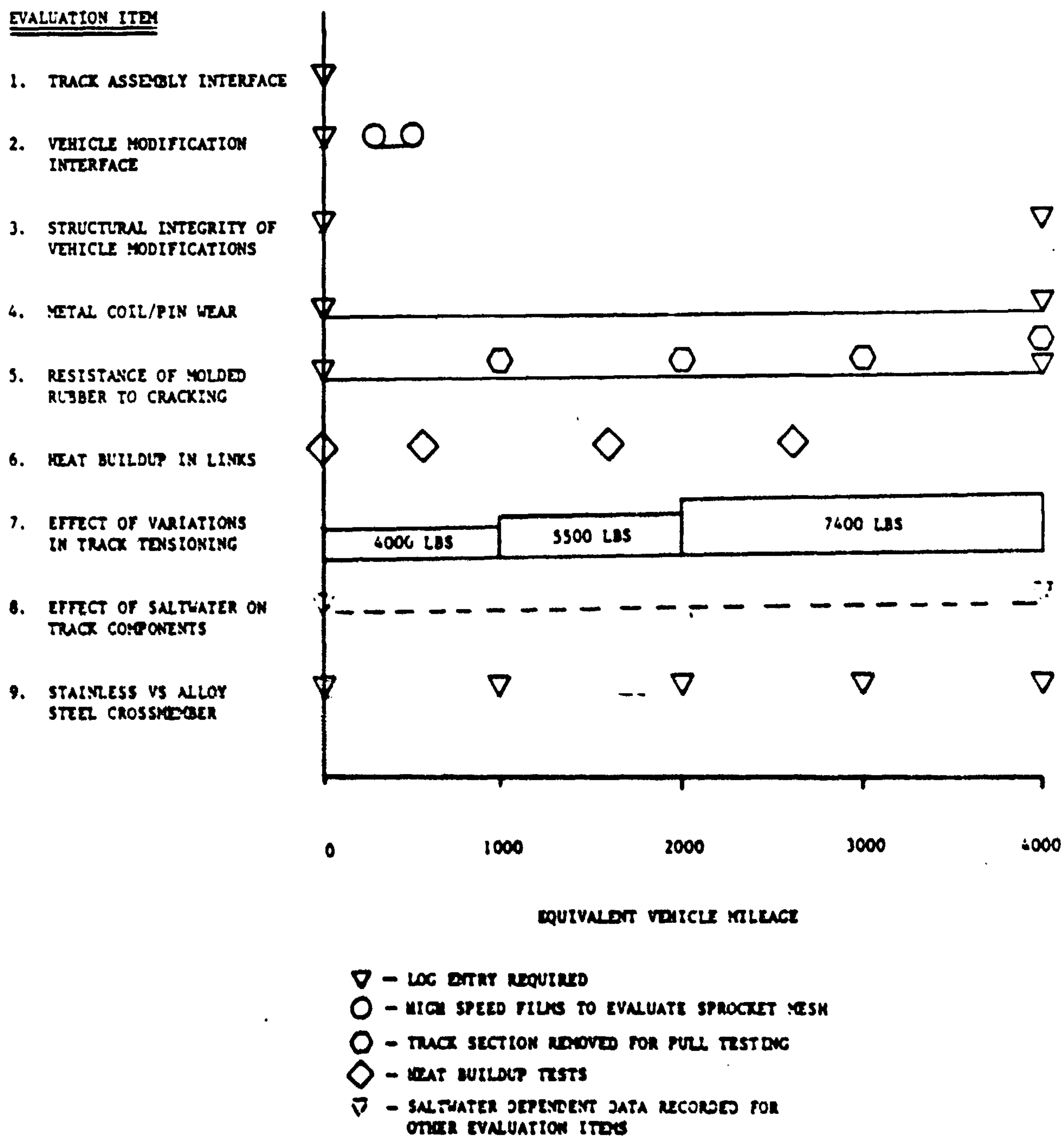


Figure 3.0-1 LABORATORY TRACK TESTING SCHEDULE

Appendix F

Wire Link Track Laboratory Test Results and Analysis

Preface

The AAI Engineering Report No. 13006A, "Laboratory Test Plan of Improved Performance Band-Track Components" provides detailed information concerning the laboratory test. Included in ER-13006A is a discussion of the objectives, the testing machine, the testing rationale, and the test procedures. The information contained in ER-13006A is essential to the interpretation of the test results which are presented in this report and should be reviewed prior to reading this report.

1.0 Status Summary

The laboratory testing of the wire link band track components was begun on November 8, 1983 and completed on December 12, 1983. During this time, the wire link track components completed 1050 equivalent flexure miles at a constant speed of 27 MPH with a constant track tension of 4000 LBS. One thousand fifty equivalent flexure miles corresponds to 1,192,000 flexings of each rubber block in the test loop and 596,000 sprocket engagements with each crossmember. At the conclusion of testing, the following general comments concerning the condition and performance of the track components are noted:

1. The pitch length of each track section was closely monitored during the laboratory testing. At the conclusion of testing, the average pitch length was 5.92 inches which is a growth of 0.11 inches.

2. Of the three rubber compounds tested: Old R-281, New R-281 and R-230 all experienced rubber cracking failures with the Old R-281 performing the best.

3. The overpitched sprocket caused accelerated wear of the crossmember driving lugs. The stainless steel crossmembers wore at 3.8 times the rate as those made from carbon steel.

4. Due to the short duration of testing, little concerning saltwater exposure was determined. Only surface rust has been detected.

2.0 Deviations From Test Plan

During the course of the laboratory test it was necessary to omit several procedures. These omissions were as follows:

1. Concluded testing at approximately 1000 equivalent miles. The test plan provided for a total test mileage of 4000 miles.

2. The track tension was never increased above 4000 pounds. The test plan specified that the track be run at a tension of 4000, 5500, and 7400 pounds.

3. High speed films of the sprocket engagement were never taken.

4. Destructive testing of the crossmembers was never performed.

5. Sectioning of the drive lugs of the stainless and carbon steel crossmembers was not done.

3.0 Results and Analysis of Evaluation Details

3.1 Track Assembly Interface

3.1.1 Results

All critical interfaces on the link assembly were evaluated prior to delivering these components to Standard Products Co. to have them molded in rubber. All interfaces on the link assemblies were found to be acceptable.

The final track assembly interface was evaluated after the link assemblies were molded into rubber and after the crossmembers were machined. Due to excessive warpage of the crossmember the rubber molded blocks interferred with the crossmember at assembly.

Several incidences of bolts galling inside end connectors were also recorded during installation and removal of the bolts.

3.1.2 Analysis

The crossmember warpage problem was analyzed in detail in order to determine a short term solution for the laboratory test machine quantity. Modifications to the sandcasting drawing will be made in order to eliminate excessive warpage in the production quantity.

The warpage of the crossmember was a result of unbalanced shrinking of the metal during the casting process.

The short term solution for the laboratory test quantity of crossmembers was to machine the sides of each crossmember as shown in Figure 1. On some crossmembers this clean-up operation was minimal. On severely warped crossmembers a large amount of metal was removed.

To avoid galling of the stainless steel bolts in the stainless steel end connectors, an anti-galling compound was applied to the bolts. Five out of two hundred thirty bolts still had galling problems. The threads in the end connectors were retapped and new bolts were inserted with no further problems. On no occasion did any of the bolts on the test machine work themselves loose.

3.2 Track Installation Interface

3.2.1 Results

The meshing of the track with the drive sprocket was very rough at the beginning of testing. The meshing progressively got smoother and

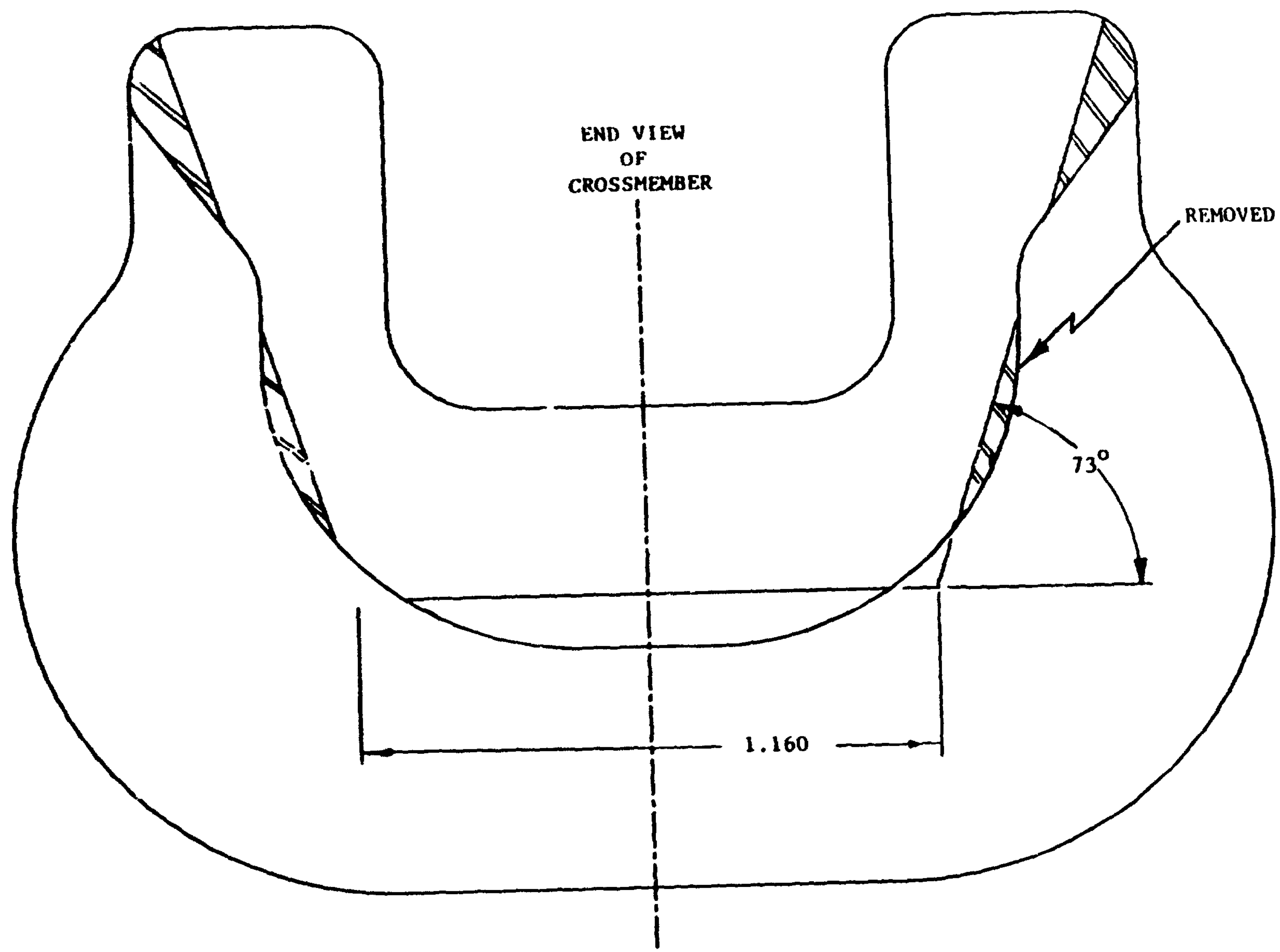


Figure 1 Material Which Was Removed From Crossmembers to Provide Clearance for Rubber Molded Block

smoother as the track approached perfect pitch. The sprocket meshed on the leading side of the crossmember. Initially silicone grease was used to help the track slide on the support tires. To further minimize excessive crossmember drive lug wear, the sprocket support wheel diameter was reduced. This greatly improved sprocket mesh.

3.2.2 Analysis

To understand the meshing problem encountered on the laboratory test machine a brief discussion concerning sprocket design is provided. The wire link track sprocket wheels and support tires are designed to provide 0.10 inch underpitched track. In this case, the sprocket teeth are spaced 0.1 inch further apart than the unworn track. This pitch relationship changes with times as wear increases the track pitch. In effect, an initially underpitched track will pass through the condition of correct pitch and continue to increase in pitch as a result of wear and become overpitched.

Consideration must also be given to the conditions of sprocket driving, sprocket idling (or slack track), and sprocket being driven by the track (or braking - due to such actions as steering, deceleration, and descending a slope). These various conditions will be discussed in more detail for the underpitch track.

A sprocket starting to drive an underpitched track encounters no difficulty at the beginning of contact since the arriving link fits easily into a tooth space and is free to gradually slip backward in the tooth space and contact a driving tooth face as the sprocket rotates.

The relationship of an underpitched track on a sprocket not subject to tractive effort is somewhat different since the track is slack. With a slack track the track drive lug floats freely in between the teeth as the sprocket rotates.

The condition with the sprocket braking is most severe. The arriving link contacts the rear face of a sprocket tooth at a considerably greater radius than is normal. The only available force to counteract this (i.e., pull the link toward the tooth root) is the tension on the slack side of the track minus the friction component. As any one link slides out to a larger radius, the amount of underpitching is exaggerated. Each succeeding link tends to slide further toward the tooth tip.

The track on the test machine simulated the sprocket braking condition. This is due to the high sliding friction of the rubber on steel. The tooth force required to slide the track on the support wheel with a 4000 pound track tension is:

$$P_1 = P_2 \; e^{f\phi} \quad .35$$

$$= 4000 \, e^{.35\pi}$$

$$= 12000 \text{ LBS}$$

To reduce this force, silicone grease was applied to the track and the sprocket support tires were reduced in diameter to provide a 0.05 inch underpitch track rather than a 0.10 inch.

3.3 Interface and Structural Integrity of Vehicle Modification

3.3.1 Results

All vehicle modification components were easily installed. The idler wheel concentricity was checked using a dial indicator. At the beginning of testing the inner wheel was concentric $\pm.010$ inches while the outer wheel was concentric $\pm.020$. This was checked at the conclusion of testing and found to be the same.

3.3.2 Analysis

It can be concluded that all vehicle modification parts performed well and no structural modifications are required.

3.4 Metal Coil/Pin Wear

3.4.1 Results

Three indications of metal coil/pin wear were recorded. These were: 1) pitch length growth, 2) tensile testing, and 3) physical inspection.

The pitch length was measured at the end of each testing day. Figure 2 is the average pitch growth as a function of hubodometer miles. to obtain equivalent flexure miles from hubodometer mileage multiply by .7569.

The pitch length was measured in two locations on each section. These measurements were taken across the inboard and outboard sides of the track. The measurements showed that the inboard track band grew more than the outboard side. At a hubodometer mileage of 600 miles, the track was reversed so that the inboard band moved to the outboard side. This was done to extend the life of the crossmembers which had experienced excessive wear on the drive lug. Figure 3 shows the relative pitch growth of the inboard and outboard bands for both standard and tight weave wire mesh blocks. The tight weaved wire experienced less pitch growth than the standard wire. Band A, from the figure, was installed on the inboard side at the start of testing then was switched to the outboard side as described above.

Destructive tensile testing was performed on new and worn rubber molded track blocks. Pull tests were also performed on the end connectors. Appendix A contains the complete data from the pull tests conducted by Penniman and Browne, Inc., an independent testing laboratory. Table 1 below is a summary of the findings:

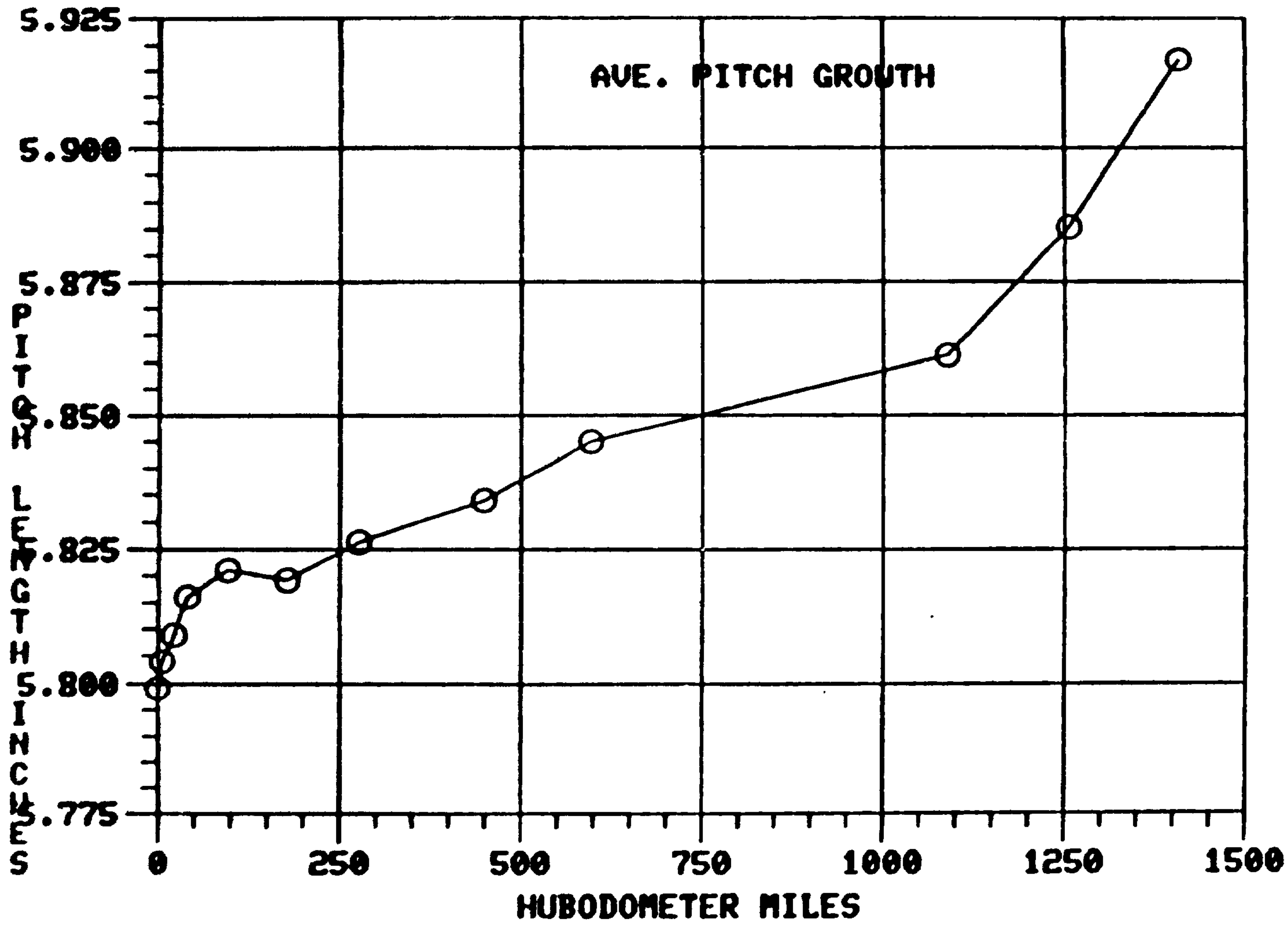


Figure 2 Pitch Growth Due to Wear During Testing

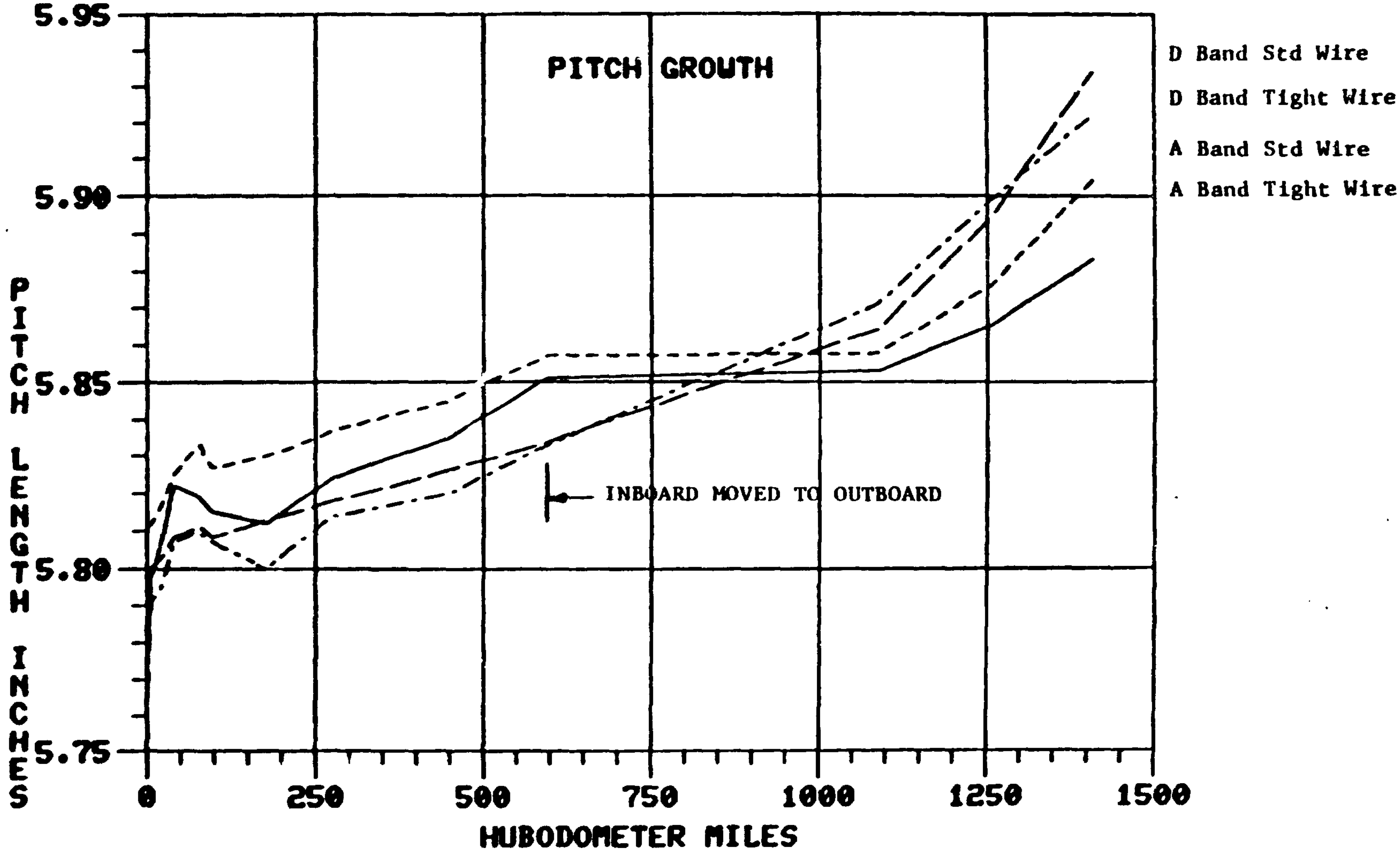


Figure 3 The Inboard and Outboard Bands
Wore Nonsymmetrically

Table 1 Tensile Test Summary

Block No.	Block Width	Length, in	Hubodometer Mileage	Cracking Load, LBS	Ultimate Load, LBS
	Track Blocks				
New	Narrow	5.81	—	19,750	20,675
New	Wide	5.81		30,500	31,100
23D	Narrow	5.86	1088	19,000	20,000
23C	Wide	5.87	1088	29,500	31,500
21A	Narrow	5.890	1400	17,000	17,000
1A	Wide	5.885	1400	18,000	18,500
	End Connectors				
New	Narrow		—		27,400
New	Narrow				27,600
18D	Narrow		1400		17,900
11B	Wide		1400		40,600
17C	Wide		1400		38,800

All used molded block samples tested failed in the wire mesh on the male end connector end. The unused block failed in the center wire. All end connector pairs failed on the large hole end of the female end connectors.

For physical inspection purposes, the rubber was removed from 11 rubber blocks. The observations which were made are given in Table 2 for each of the blocks.

Table 2

Physical Inspection Summary

Block No.	Block Width	Length, in.	Hubodometer Mileage	Description of Condition
4C	Wide		1400	1 broken coil, male end
11B	Wide		1400	None broke
12B	Wide		1400	None broke
13B	Wide		1400	2 end coils broken
13C	Wide		1400	1 end coil broken
17C	Wide		1400	1 broken coil, male end
18C	Wide		1400	2 end coils broken
18D	Narrow		1400	coils all broke on male end
19A	Narrow		1400	3 broken coils
23A	Narrow		1088	even wear
23B	Wide		1088	even wear

General observations concerning the physical conditions of these link assembly components are as follows:

a. Wire mesh pins showed little or no sign of wear.

b. Wire wear was more severe on the end connector ends.

c. All snap rings remained in place.

d. No wear on end connectors evident.

e. Two narrow bands (18D and 21D) experienced total failure of the wire on male end connector side.

3.4.2 Analysis

Determination of the required tensile strength of the wire link track for installation on a 14 ton tracked amphibian was established by the following conservative design criteria. The ultimate tensile capacity must be (1) greater than 5 times the maximum tractive effort or (2) two times the gross vehicle weight, whichever is greater. In this case, the tractive effort calculation resulted in the higher tensile requirement of 64,000 pounds (5 x 12,800) (12,800 = projected ATR tractive effort/2). The tensile testing of the track blocks showed that the total ultimate tensile capacity of the wire link track assembly is above the design requirement through the 1050 miles tested. The following conditions of wear are noted in the summary shown in Table 3.

The difference between the pitch growth of the inboard to the outboard track block has been attributed to nonsymmetric loading of the track. This was due to the dynamic flexure of test setup. Most of flexing probably has occurred at the idler spindle. The effect of the dynamic flexing of the idler spindle is to relieve the outboard bands of the back tension thereby forcing most of the tensile load into the inboard bands. The effect of this dynamic flexing is quite exaggerated on the test setup since the span between the sprocket wheel and the idler is quite short. For a larger span, such as is on an M113 vehicle, the effects of this flexing will be minimal.

Two related factors caused the inboard (more highly loaded) band to wear at higher rate than the outboard bands. These factors are pressure and temperature. The higher pressure at the wire to pin interface caused a higher wear rate since wear is a function of pressure. This high pressure caused more friction which built up heat. Wear rates increase with temperature due to a decrease in metal hardness.

Physical inspection of derubberized test blocks revealed that virtually all metal wear which caused pitch growth occurred in the wire mesh. The surface of the pins and end connector showed little, if any, sign of wear. The majority of the wire wear occurred at the end connectors indicating the higher rotation of the wire relative to the pin is the cause. This, however, is unavoidable since the chord length of the end connectors is twice that of a wire link.

Table 3. Tensile Strength of Track Assembly

Hubodometer Mileage	Flexure Mileage	Pitch Length	Tensile Capacity	M.S.
0	0	5.81	103550	.62
1088	824	5.865	103000	.58
1400	1060	5.890	71000	.11

3.5 Resistance of Molded Rubber to Cracking

3.5.1 Results

The incidence of rubber cracking for the three rubbers tested are provided in Tables 4 and 5.

The Old R291 experienced the least percentage of rubber failures. The New R281 and the R230 performed approximately equivalently. However, the New R281 experienced cracks in the center (between the rubber fingers) early in testing. No failures of this type occurred in any of the rubbers.

Up to a hubodometer mileage of 596 the track was run for periods of less than an hour. Excessive heat buildup was not permitted to occur until after 596 hubodometer miles.

Durometer checks of the samples tested revealed that the New R281 and R230 were incorrectly cured to a Durometer of 70 while the Old R281 was correctly cured to a Durometer of 63.

3.5.2 Analysis

The high incidence of rubber cracking in all of the rubber compounds raised many questions concerning the stress levels in the rubber. A NASTRAN finite element analysis has been conducted to determine the stress levels in the existing design, the effect of two configuration changes, and the effect of 63 versus 70 durometer rubber.

A two dimensional NASTRAN stress analysis, using imposed deflections, was used to determine the stress in the rubber. The imposed deflections, which are a result of .150 inches of stretching from flexing around the idler, are given in Figure 4.

The two alternate configurations shown in Figure 5 were investigated to evaluate the effect of reducing the stress concentrations at the end connector interface and at the radius in between the rubber fingers.

The results of the analysis are presented in Table 6. The grid numbers assigned to the NASTRAN model are shown in Appendix B. The deflected shapes resulting from the imposed deflections are shown in Figures 6, 7 and 8.

The conclusions of NASTRAN analysis are as follows:

- The 70 durometer rubber parts which were tested causes the stresses to increase 12 percent above the 63 durometer rubber specified.

- The increase in radius, and reduction in length of the end of the rubber cleat has little effect on the peak stresses at the ends of the rubber block. Stresses at the inboard radius are reduced by about 6 percent.

Table 4. Incidences of Rubber Cracking in Wide Blocks

WIDE BLOCKS

HUBODOMETER MILEAGE	OLD R281 QTY	OLD R281 FEMALE END QTY	%	OLD R281 MALE END QTY	%	OLD R281 CENTER QTY	%	OLD R281 TOTAL QTY	%	NEW R281 QTY	NEW R281 FEMALE END QTY	%	NEW R281 MALE END QTY	%	NEW R281 CENTER QTY	%	NEW R281 TOTAL QTY	%	R230 QTY	R230 FEMALE END QTY	%	R230 MALE END QTY	%	R230 CENTER QTY	%	R230 TOTAL QTY	%
275	8									24					4	17		5.7	14								
440	8									24					10	41		14	14								
596	8									24					11	46		15	14								
1000	8	1	13						6.3	24					11	46		15	14	7	50						17
1257	8	2	25	1	13				13	22	4	18			9	41		20	14	10	71	4	29				27
1487	8	2	25	3	38				21	22	10	45	5	23	9	41		36	14	11	79	7	50				43

Table 5. Incidences of Rubber Cracking in Narrow Blocks

NARROW BLOCKS

HUBODOMETER MILEAGE	OLD R281 QTY	OLD R281 FEMALE END QTY	%	OLD R281 MALE END QTY	%	OLD R281 CENTER QTY	%	OLD R281 TOTAL QTY	%	NEW R281 QTY	NEW R281 FEMALE END QTY	%	NEW R281 MALE END QTY	%	NEW R281 CENTER QTY	%	NEW R281 TOTAL QTY	%	R230 QTY	R230 FEMALE END QTY	%	R230 MALE END QTY	%	R230 CENTER QTY	%	R230 TOTAL QTY	%
275	8									24									14								
440	8									24									14								
596	8									24									14								
1000	3									24									14								
1257	8									22									14								
1487	8	1	13%						4%	22			2	9%				3%	14			5	36%				12%

MOVEMENT DUE TO .150 STRETCH AND DUE TO FLEXING ON IDLER

GRID NO	DELTA X	DELTA Y
7	.1034	-.0762
8	.1078	-.0955
12	.0828	-.200

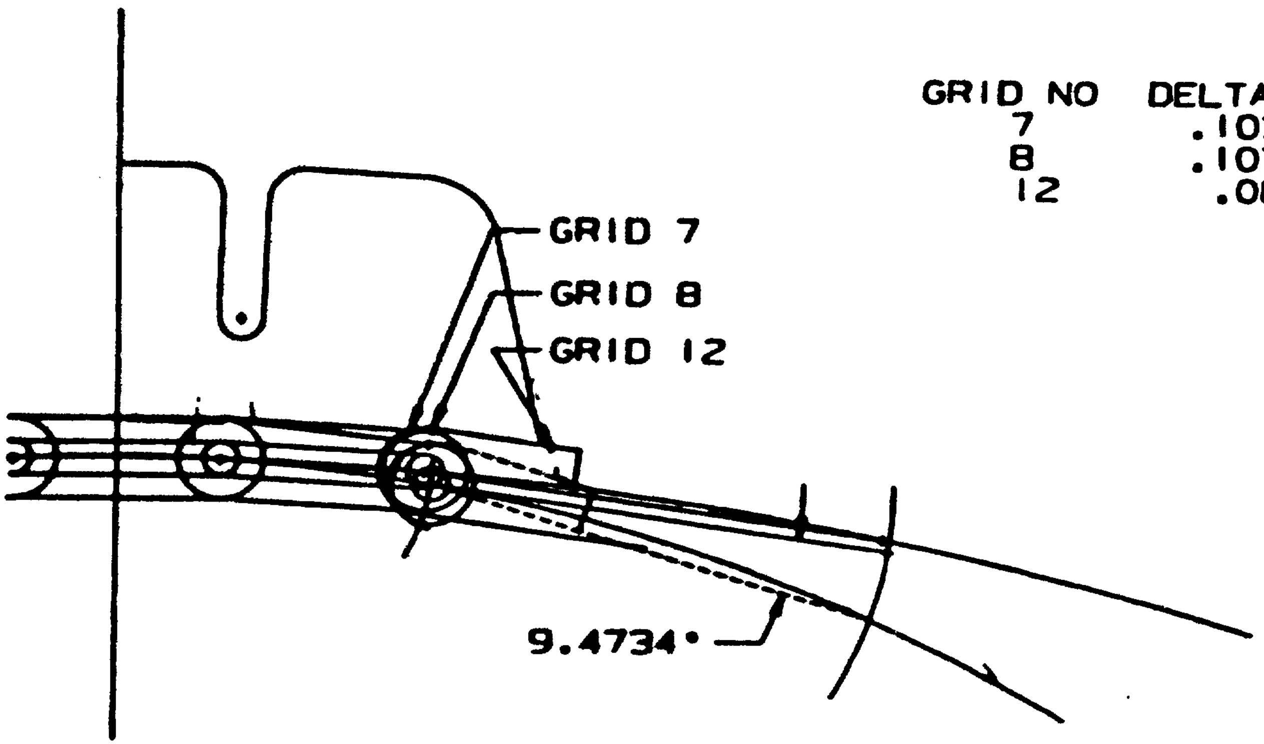
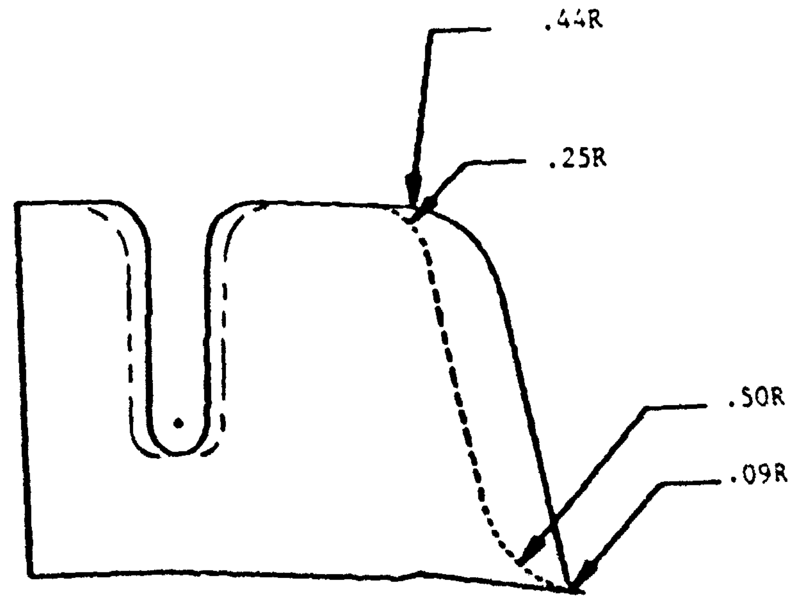


Figure 4 Movement Due to .150 Stretch of Mesh Combined with Flexing on Idler



SOLID LINE: CURRENT CONFIGURATION
DASHED LINE: MODIFIED END RADIUS CONFIGURATION
PHANTOM LINE: MODIFIED CENTER RADIUS CONFIGURATION

Figure 5 Rubber Configuration Changes Which Were Analyzed

Table 6. Results of NASTRAN Analysis

Stress Summary

Current Configuration

EID	Principal Stress (psi)		EID	Max Shear (psi)	
	Du = 63	Du = 70		Du = 63	Du = 70
16	106.5	119.2	16	43.7	48.9
17	97.0	108.6	39	39.5	44.2
56	68.6	76.8	17	38.7	43.4
59	68.5	76.7	32	35.3	39.6
98	64.8	72.6	98	33.4	37.4

Alternate Configuration - End

EID	Principal Stress (psi)		EID	Max Shear Stress (psi)	
	Du = 63	Du = 70		Du = 63	Du = 70
16	100.2	112.1	16	41.2	46.2
17	87.0	97.4	39	39.2	43.9
97	60.8	68.1	17	35.8	40.1
89	60.4	67.6	32	35.5	39.7
31	60.0	67.2	40	30.2	33.8
126	68.6	76.8	126	35.7	39.9

Alternate Configuration - Center

EID	Principal Stress (psi)		EID	Max Shear Stress (psi)	
	Du = 63	Du = 70		Du = 63	Du = 70
16	84.3	94.4	16	37.1	41.5
17	80.5	90.1	39	38.9	43.5
56	66.9	74.9	17	34.4	38.5
59	67.0	75.0	32	34.9	36.2
98	63.5	71.1	98	32.7	36.6
216	95.4	106.8	216	43.4	48.6
296	63.2	70.7	296	25.2	28.2
226	52.2	58.5	226	22.4	25.1

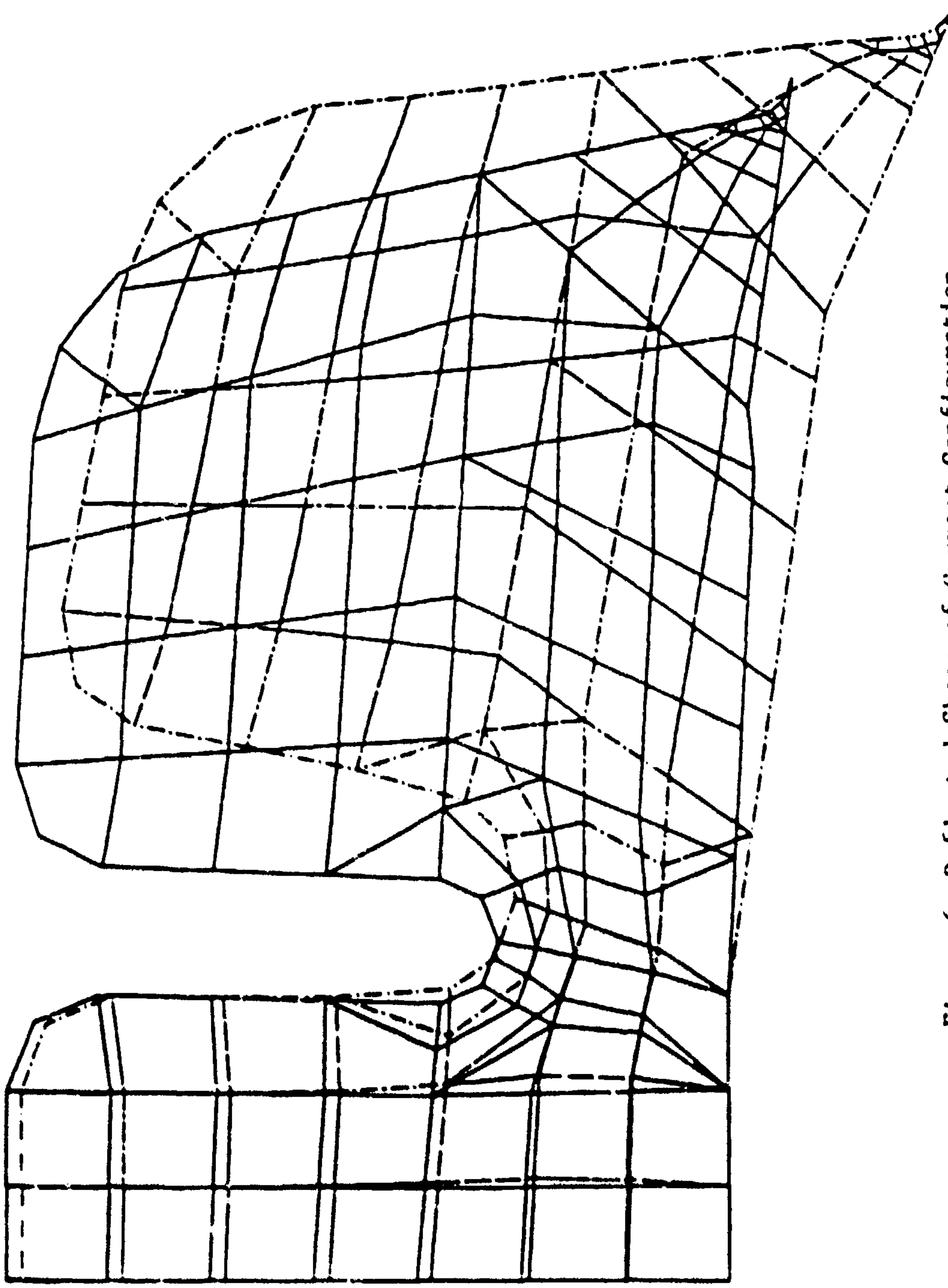


Figure 6 Deflected Shape of Current Configuration

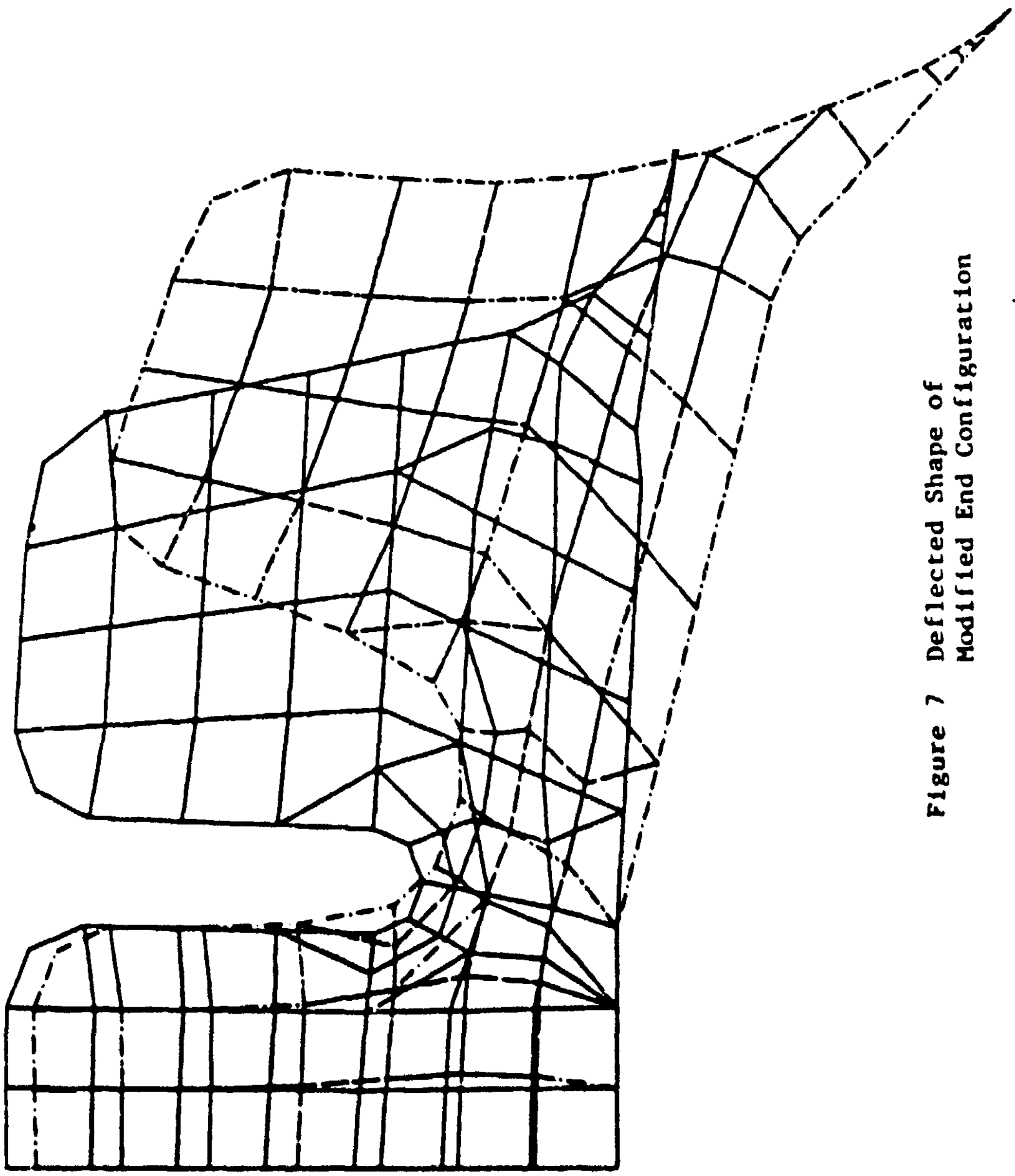


Figure 7 Deflected Shape of
Modified End Configuration

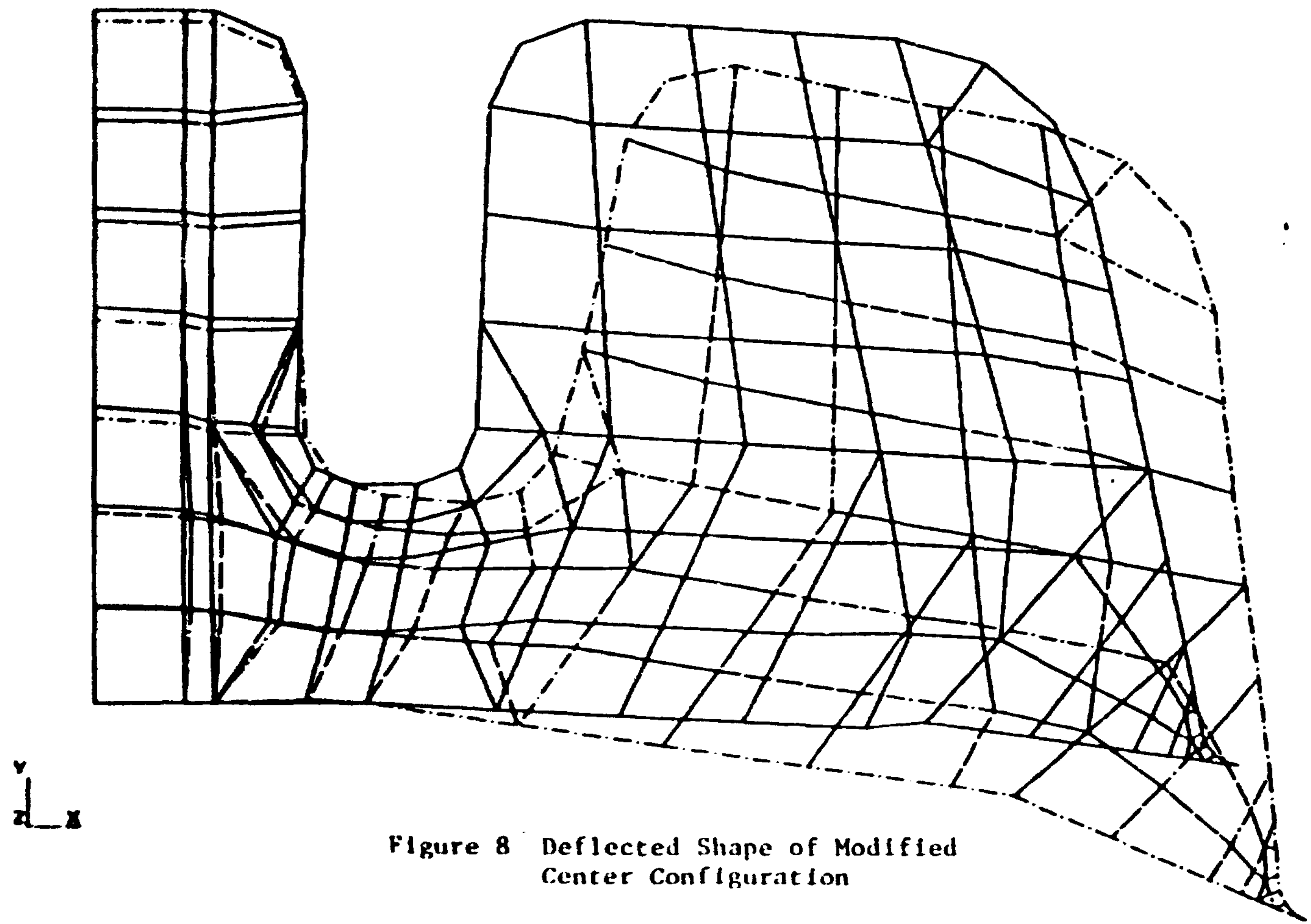


Figure 8 Deflected Shape of Modified Center Configuration

- Increasing the spacing between cleats by 1/8 inch reduces stresses at the inboard radius by 12 percent. Stresses at the ends of the rubber block are reduced by less than 2.5 percent.

- The maximum calculated stress in the rubber was 119.2 psi. At 1,000,000 cycles of loading (corresponding to 1050 flexure miles), the fatigue stregth of the rubber should be approximately 375 psi (See Figure 9). However, fatigue life is significantly degraded as temperature is increased as shown in the accompanying Figure 10.

3.6 Heat Build in Links

3.6.1 Results

A large amount of heat was generated within the wire link track during laboratory testing. This was aggravated by the installation of a insulated plywood box enclosure over the test machine. The box was required for safety and acoustical considerations for operation in a busy shop area. A fan was used to circulate air over the track. Still the ambient air within the box was recorded to reach 120-140°F.

Temperature measurements were recorded at two mileages during the laboratory test: 952 and 1200 hobodometer miles. The data, which is presented in Table 7, is the steady state temperatures. These measurements were taken after extended run times.

To obtain temperature readings within the track blocks, the exposed portion of the wire mesh pins were used to detect the rubber temperature at the mesh flexing point. The highest temperature recorded was 257°F which was detected at the inboard narrow track block. Since much more wear was found to have occurred at the end connector pins, higher temperatures probably occurred at the end connector pin.

3.6.2 Analysis

The rubber temperatures which resulted from heat build-up had a detrimental effect on track rubber life. Temperature above 200°F begins to further vulcanize the rubber resulting in a decrease of fatigue strength. Several conditions may have contributed to excessive heat build-up are:

1. Elevated ambient temperature.

2. Frequent sprocket engagements generating extra heat due to frequent sliding of the rubber on the support wheels and overload of the wire mesh to cause sliding.

3. No symmetrically loading of track bands.

4. No conductive heat loss available.

strength will continue to elongate with time and eventually will rupture. This process is known as *static fatigue;* it is the end result of the creep process. Dynamic fatigue occurs in a specimen subjected to an alternating stress centered about zero. In most vibration isolators, the fatigue process is some combination of static and dynamic fatigue. The results of an investigation of the dynamic fatigue characteristics of 50 durometer isolators strained in tension and compression are shown in Fig. 35.11. Dynamic fatigue life is plotted as a function of the per cent minimum strain, for fixed values of dynamic strain. The latter two parameters are computed in the following way. The per cent minimum strain is

$$\frac{l_{min} - l_0}{l_0}(100) \qquad \text{per cent} \qquad (35.7)$$

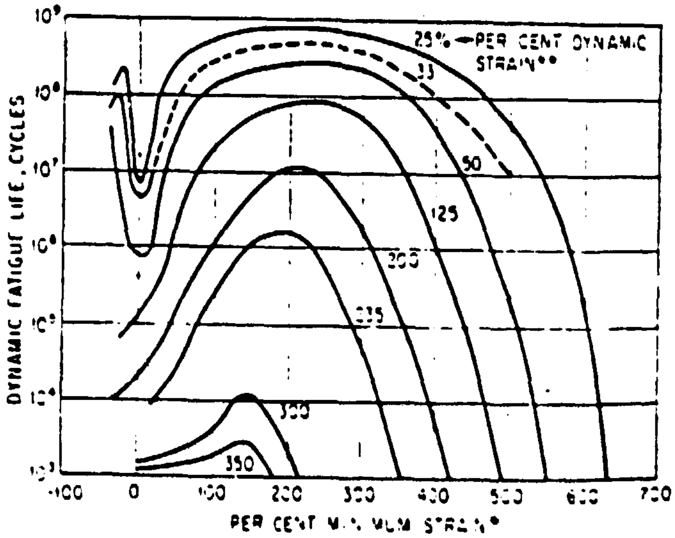


Fig. 35.11. The effect of strain on fatigue life of rubber specimens tested in tension and compression. [illegible] Morrill, Sonnen and Yost[?].

and the per cent dynamic strain is

$$\frac{l_{max} - l_{min}}{l_0}(100) \qquad \text{per cent} \qquad (35.8)$$

where l_0 is the unstrained length of the specimen, l_{min} is the minimum strained length, and l_{max} is the maximum strained length. Figure 35.11 shows that (1) for small strains there is a pronounced minimum in the fatigue life when the sample is returned to zero at the end of the stroke; (2) the point of maximum fatigue life shifts toward lower minimum strain as the dynamic strain is increased; and (3) fatigue life decreases as dynamic strain is increased. This latter effect may be caused partially by the greater heat generated. Specimens tested in shear also have a minimum life when returned to zero strain at one end of the stroke.[17] A summary of the fatigue life of shear specimens as a function of dynamic strain is given in Table 35.5.

Table 35.5. Fatigue Life in Cycles of Shear Specimens as a Function of Dynamic Strain for Various Lateral Strains[12]

Dynamic strain, per cent	Lateral strain		
	Zero	12.5 per cent compression	25 per cent tension
−25 to +25	7×10^6	20×10^6	12×10^6
0 to 50	1×10^6	2×10^6	2×10^6
75 to 125	15×10^6	2×10^6	40×10^6

Stress concentrations reduce the fatigue life of rubber isolators. Sudden changes in rubber section, sharp-edged inserts, protruding boltheads, and weld flash should be avoided. In many cases, fatigue failures will develop inside the rubber at some distance from the sharp edge of a metal insert.

Figure 9 Dynamic Fatigue Life of Rubber

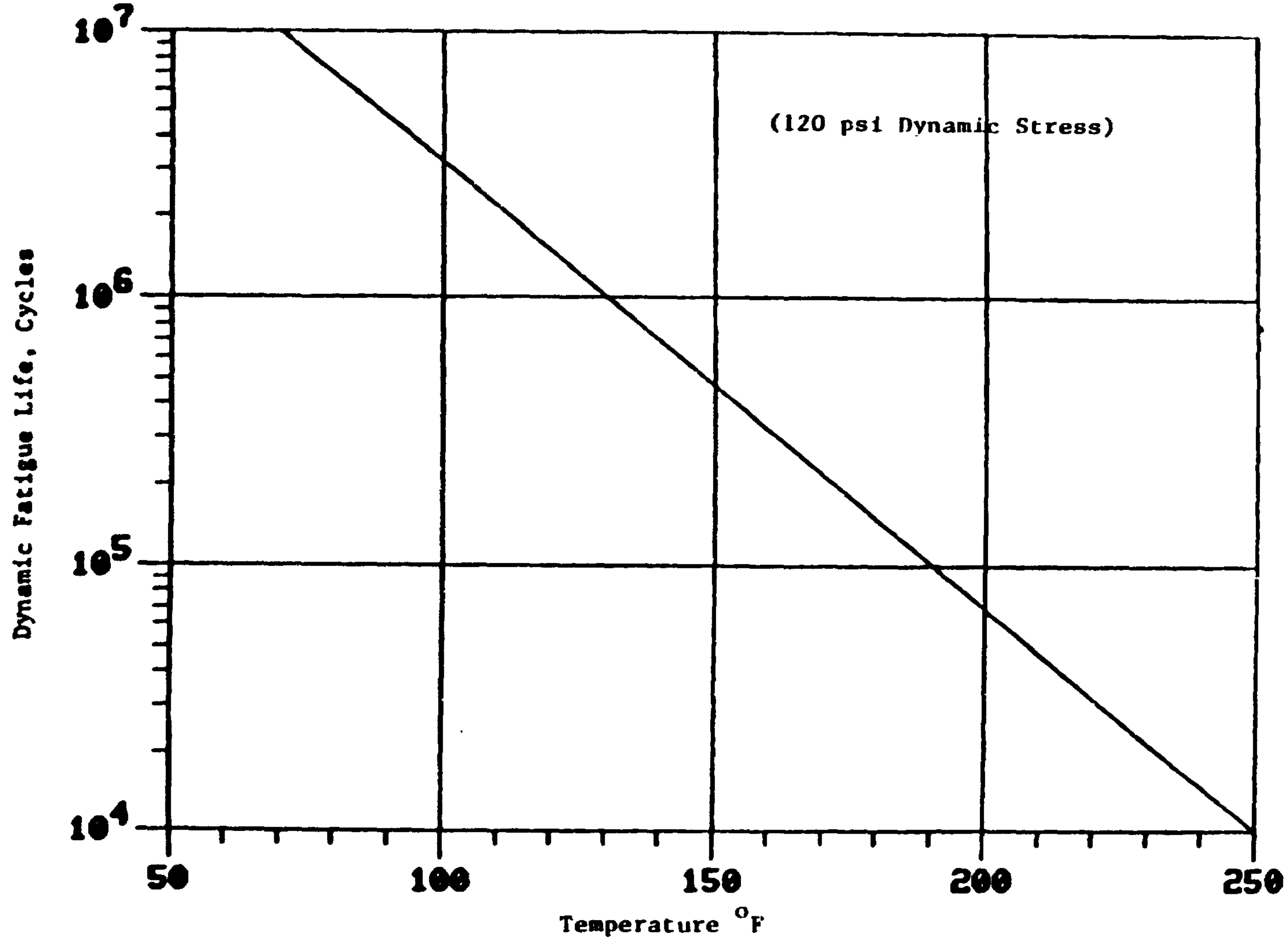


Figure 10 Fatigue Life As A Function of Temperature

Table 7. Heat Build-Up Data

Hubodometer mileage - 951.8

Air Temp. - 71.6°F

Wheel Surface Temperature °F

Outer band narrow	116.6
Outer band wide	134.6
Inner band wide	134.6
Inner band narrow	134.6

Band	Section		
	2	4	22
A	107.6	107.6	116.6
B	140	145	152.6
C	149	145.4	159.8
D	127.4	127.4	131.1

Hubodometer mileage - 1200

Air Temp. - 73.4°F

Exhaust Temp. - 127°F

Wheel Surface Temperature °F

Outer band narrow	176
Outer band wide	201.2
Inner band wide	221
Inner band narrow	257

2B	215.6
4C	213.8
22C	221

5. Higher durometer rubber generates more heat when flexed.

Heat build-up data obtained from previous wire link track field testing at Aberdeen Proving Ground are presented in Figure 11. The steady state temperature recorded was 260°F measured at the end connector pin joint. This temperature data was obtained at very severe operating conditions.

3.7 Effect of Variation in Track Tensioning

The tension was never increased above 4000 pounds. Therefore, the effect of increasing track tensioning was not evaluated.

3.8 Effect of Saltwater on Track Components

3.8.1 Results

The saltwater exposure did not seem to effect the performance or condition of any of the track components. The only observation made was surface rust on the carbon steel crossmember. This, however, is not severe and did not degrade the performance of the carbon steel crossmembers.

3.8.2 Analysis

Since the saltwater tests were performed over such a short length of time absolute conclusions concerning extended exposure cannot be made. However, the exposed and unexposed components performed essentially the same and therefore all can be considered saltwater resistant.

3.9 Stainless vs Alloy Steel Crossmember Performance

3.9.1 Results

A crossmember on the laboratory test machine meshed with the sprocket 596,000 times during testing. An M113 vehicle will travel 3552 miles to obtain the same number of engagements per crossmember.

High forces are developed in the engaging sprocket teeth due to the underpitched track as discussed in Section 3.2. These high loads caused the crossmember drive lugs to wear. Figure 12 shows the comparison of the drive lug wear of 15-5 stainless versus 4330 crossmember.

3.9.2 Analysis

The 15-5 crossmembers wore more than the 4330 since the stainless steel is much more susceptible to galling. Evidence of galling was the deposits of stainless left on the teeth of the sprocket.

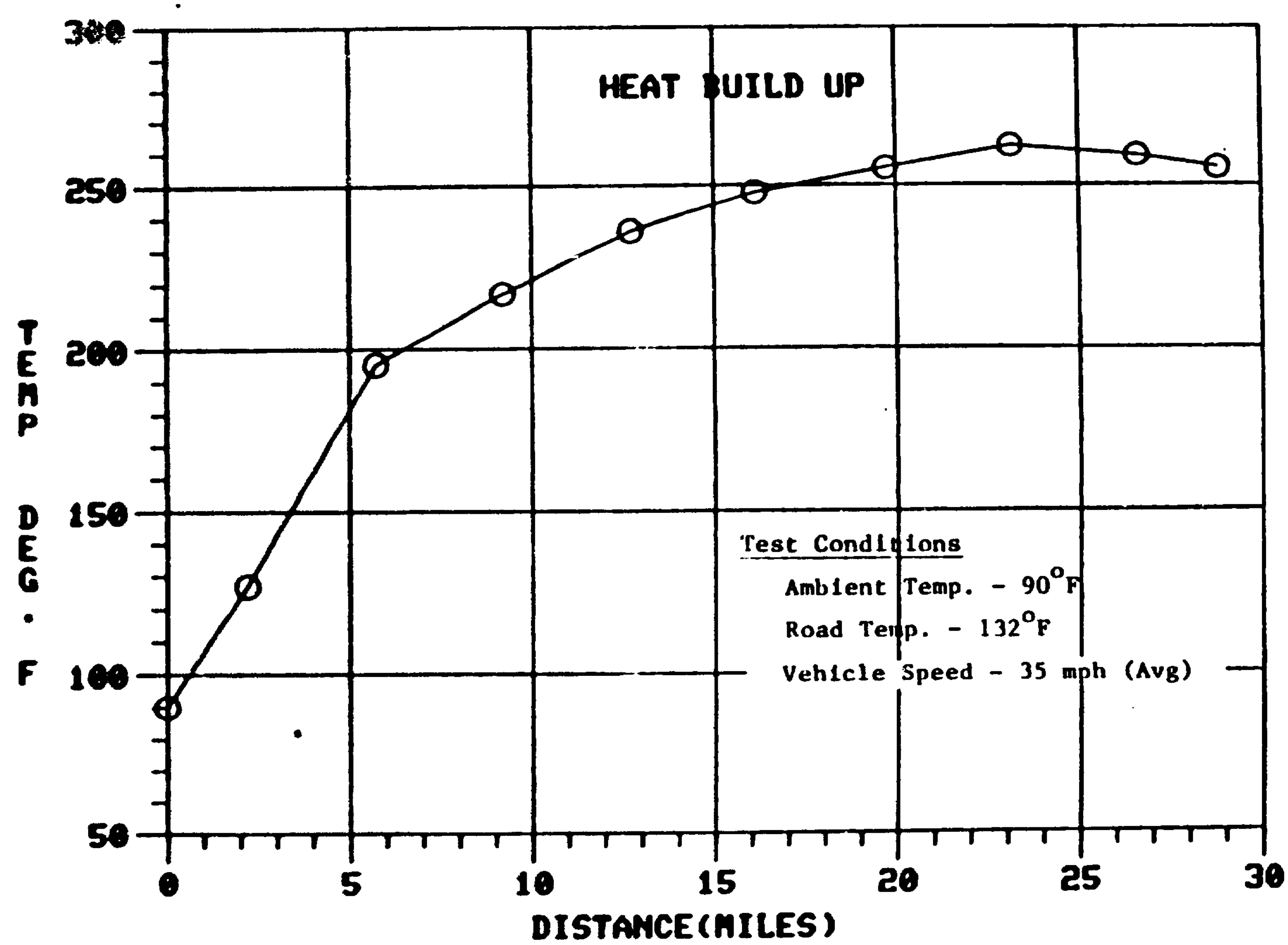


Figure 11 Aberdeen Test Results - June 25, 1963
4^{0} Modified Wire Link Track Temperature Build-up

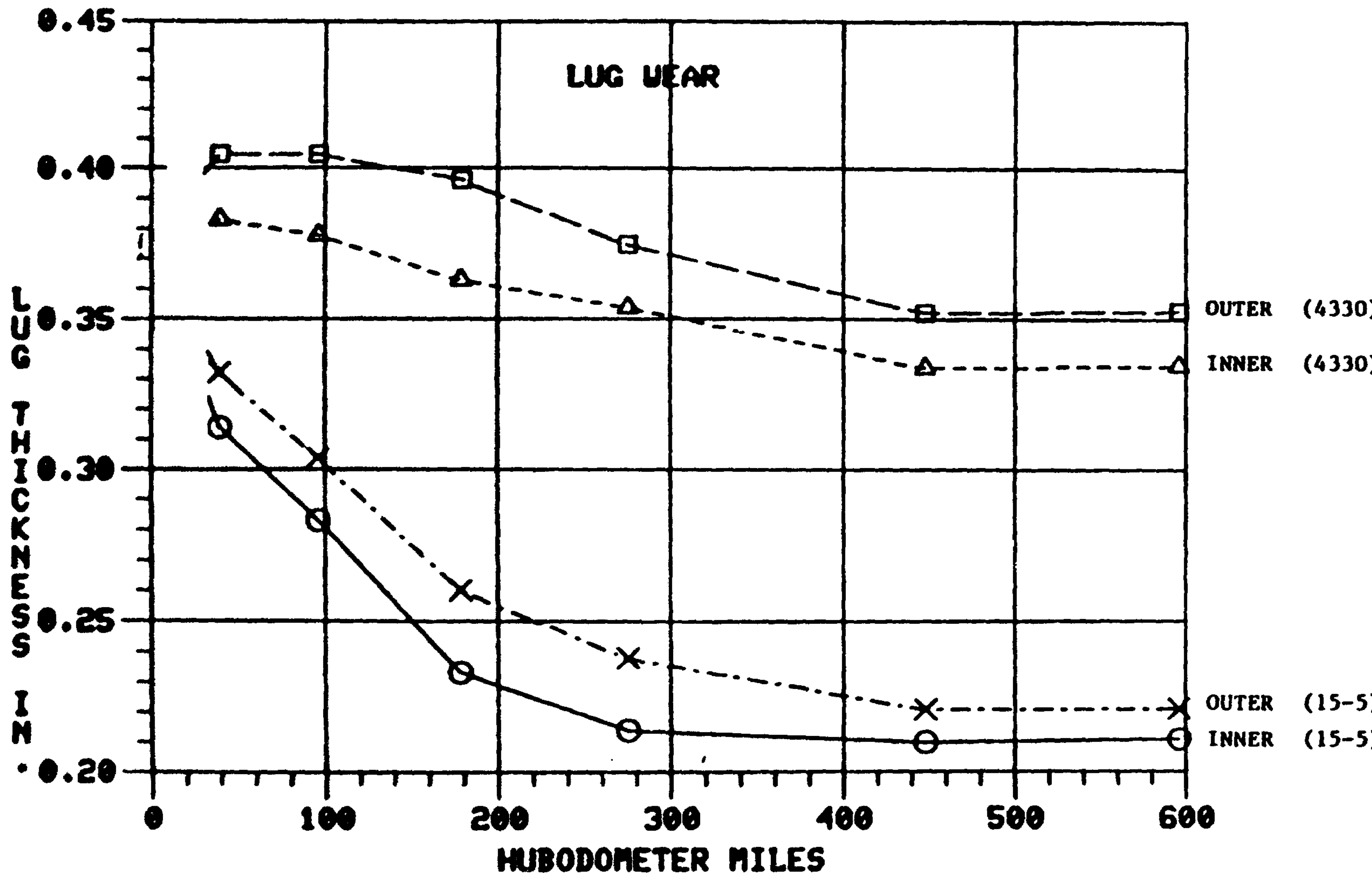


Figure 12 The Relative Drive Lug Wear of Crossmember Materials

4.0 Recommendations

At the conclusion of testing the following recommendations are made:

1. All metal components performed satisfactorily and the field test quantity of components should be ordered.

2. Carbon steel crossmembers have been selected for field testing since the stainless steel crossmember performed poorly. Modifications to the pattern are required to prevent interferences.

3. Tight weave wire should be ordered.

4. Sprocket support tires providing 0.05 inches of overpitching should be used.

5. In order to make a determination on the proper rubber compound to select, further testing will be conducted using the correct durometer rubbers with controlled heat cycles.

APPENDIX A

(Supplement to Test Results - Appendix F)

W. B. D. PENNIMAN
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1867-1932
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PHILIP M. AIDT
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NTE G. BERETTA
. ADRIAN BUTT
NALD W. SMITH

PENNIMAN & BROWNE, INC.
CHEMISTS-ENGINEERS-INSPECTORS
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BALTIMORE, MARYLAND 21209

ESTABLISHED
896
CABLE ADDRESS
"BALTEST"
TELEPHONE
825-4131
AREA CODE 301

ENGINEERING DIVISION

REPORT OF TEST

Attn: Mr. Bill Webb
P.O. 591167 January 11, 1984

No. 840065 A

Sample of Track Block Assemblies

Client AAI Corporation

Marks or Other Data Extension under load & Ultimate Load Tests of 3" Wide Block Samples

Load/Extension Tests

Load, pounds Sample	Extension, inches #1 Block 23c	#3 Block--
1000	0.000	0.000
3000	0.025	0.025
6000	0.051	0.055
9000	0.072	0.075
12,000	0.096	0.095
15,000	0.121	0.116
18,000	0.150	0.145
21,000	0.195	0.187
24,000	0.290	0.285
29,500	Crack	--
30,500	--	Crack
31,100	--	Ultimate
31,500	Ultimate	

spl

J. A. Butt

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ENGINEERING DIVISION

REPORT OF TEST

Attn: Bill Webb — January 11, 1984
P.O. 591167
No. 840065 B

Sample of Track Block Assemblies

Client AAI Corporation

Marks or Other Data Extension under load and Ultimate Load test of 2" Wide Block Samples

Load/Extension Tests

Load, pounds	Extension, inches			
Sample	#2 BL.23D	#4 BL.--	#5 BL.21A	#6 BL.1A
1000	0.000	0.000	0.000	0.000
3000	0.027	0.025	0.028	0.024
6000	0.060	0.068	0.061	0.054
9000	0.093	0.108	0.097	0.086
12,000	0.125	0.152	0.142	0.122
15,000	0.225	0.234	0.250	0.228
17,000	--	--	(Crack Ultimate)	--
18,000	--	--		Crack
18,500	--	--		Ultimate
19,000	Crack	--		
19,750	--	Crack		
20,000	Ultimate	--		
20,675		Ultimate		

spl

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ENGINEERING DIVISION

REPORT OF TEST

Attn: Bill Webb
P.O. 591167

January 11, 1984

No. 840065 C

Sample of Track Block End Connection

Client AAI Corporation

Marks or Other Data Three sets 2" Wide Marked 18D and New
Two sets 3" Wide Marked 11B and 17C

Tensile Load Tests

Sample No.	Block #	Size	Breaking Load, lbs.
7	18D	2"	17,900
8	--	2"	27,600
9	--	2"	27,400
10	11B	3"	40,600
11	17C	3"	38,800

spl

J. A. Butt

J. A. Butt

APPENDIX B

(Supplement to Test Results - Appendix F)

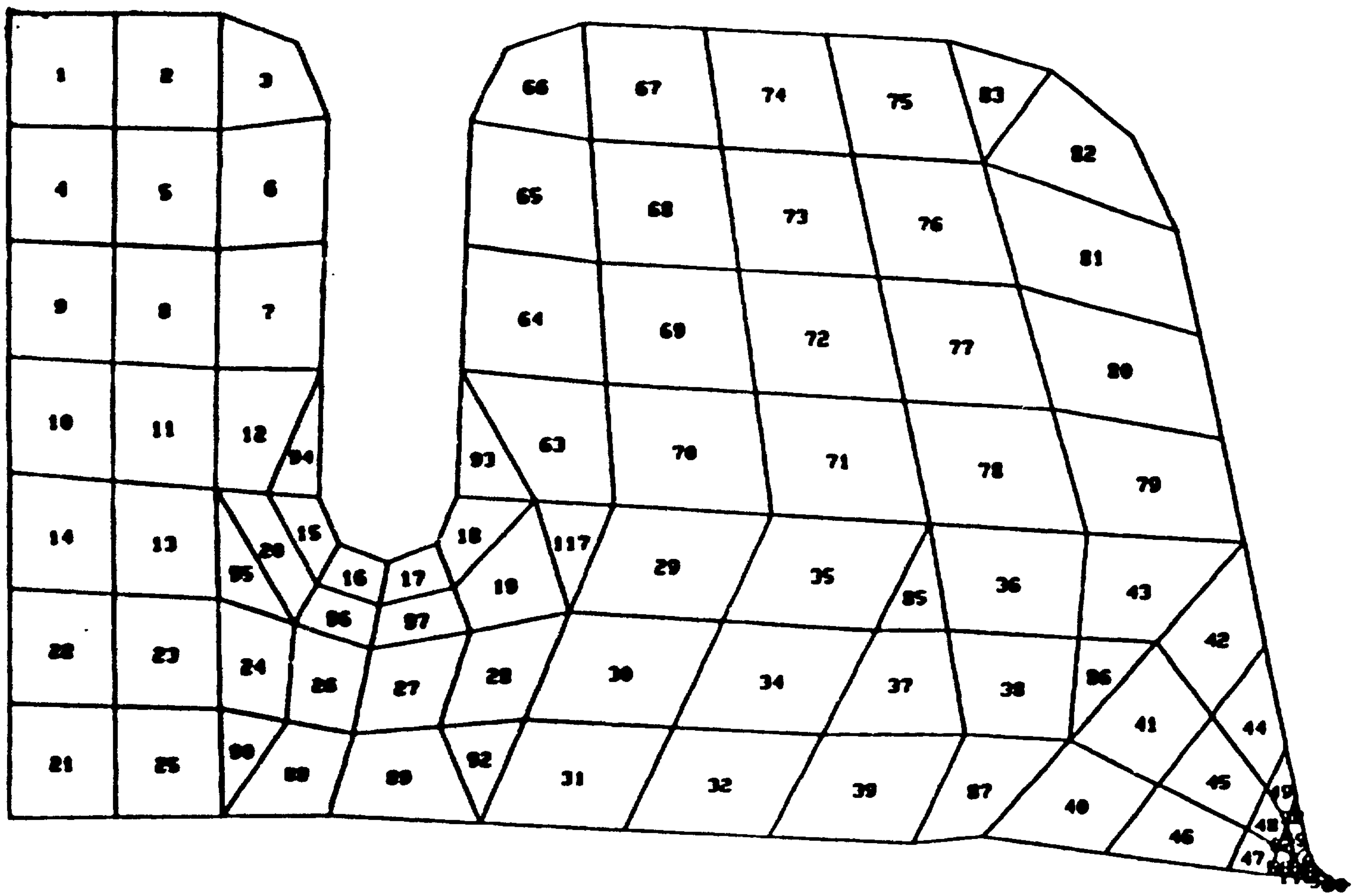

Figure 1B Current Configuration Element Numbers

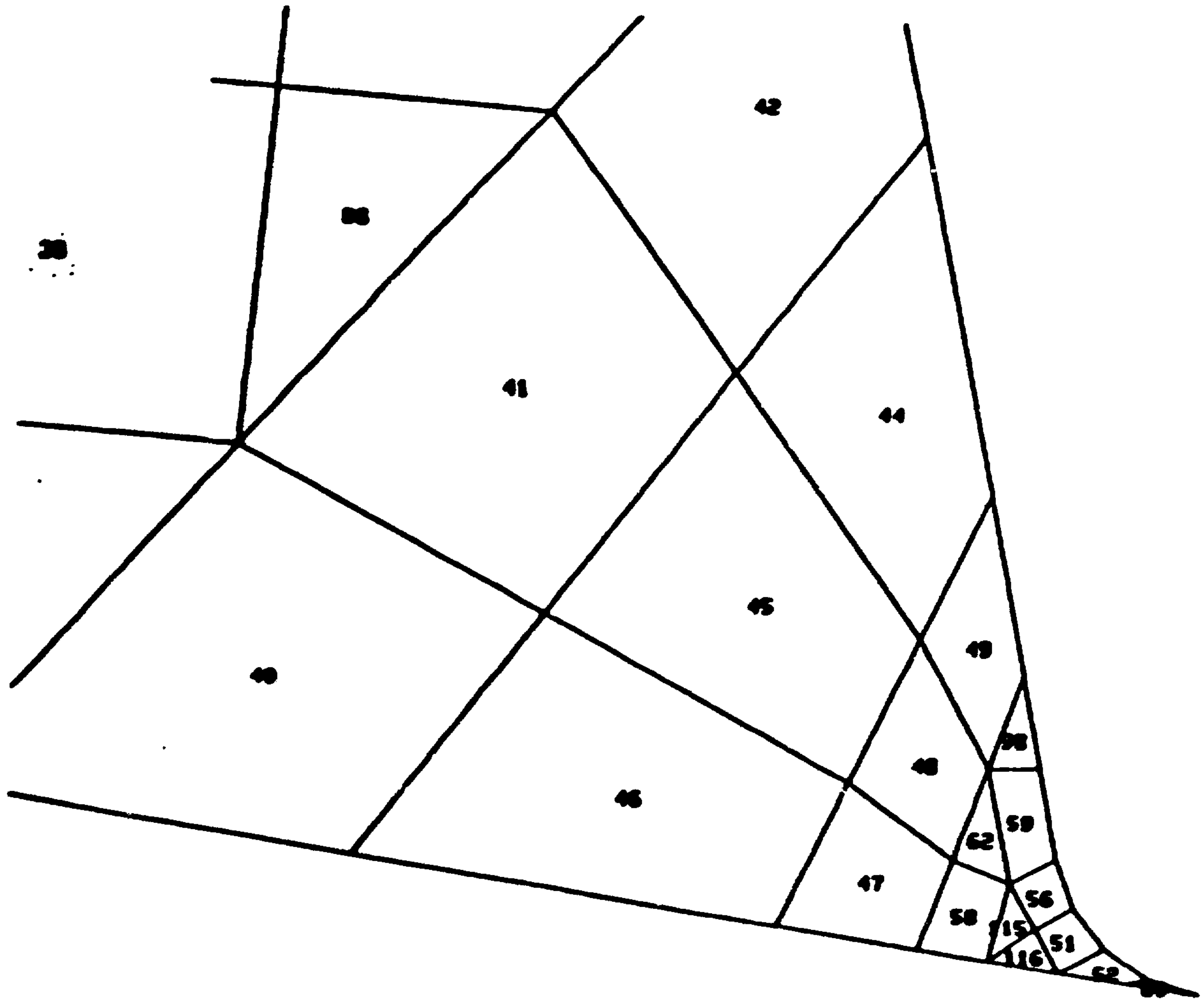

Figure 2B Current Configuration Element Numbers at End Radius

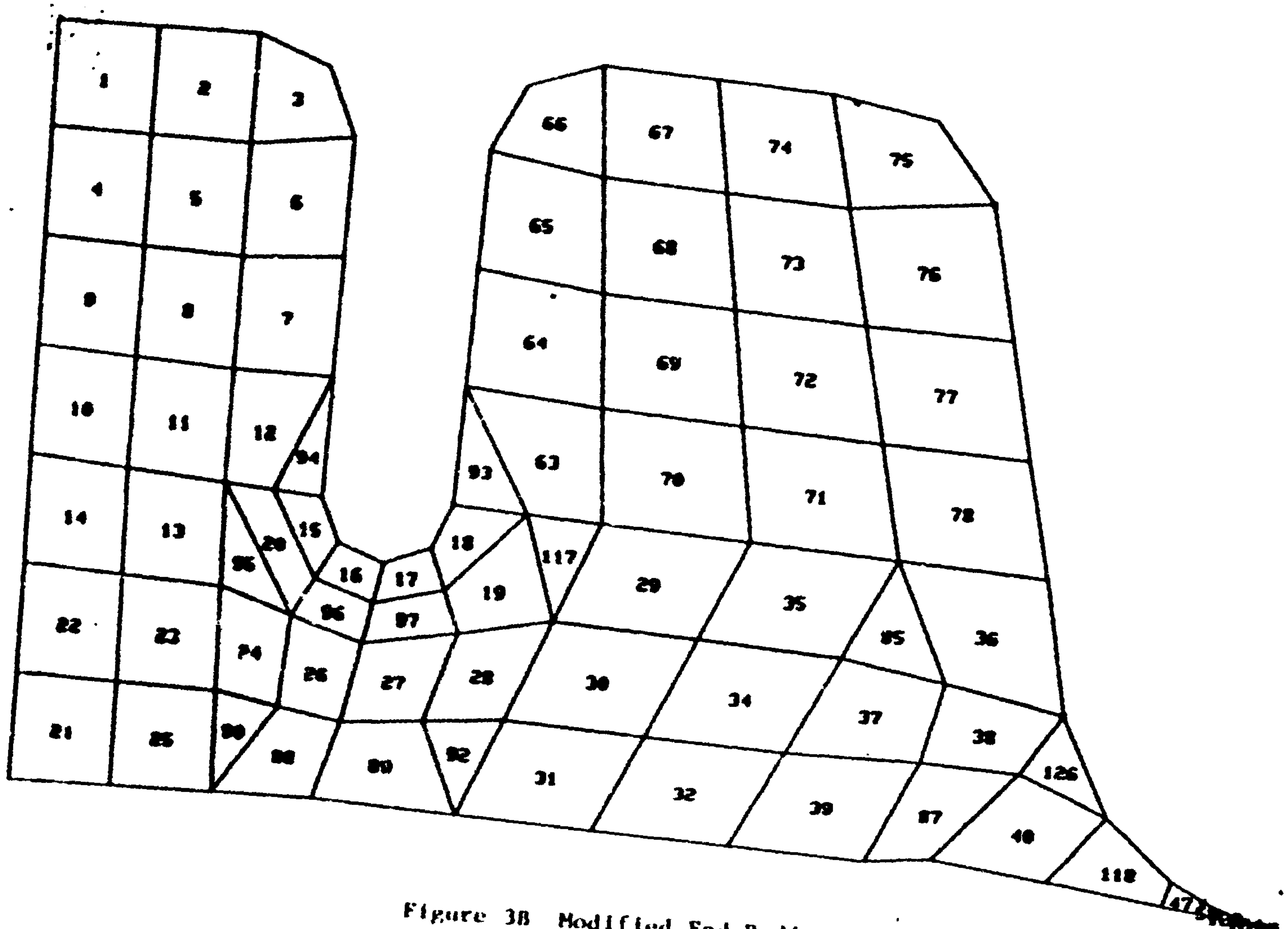

Figure 38 Modified End Radius
Configuration Element Numbers

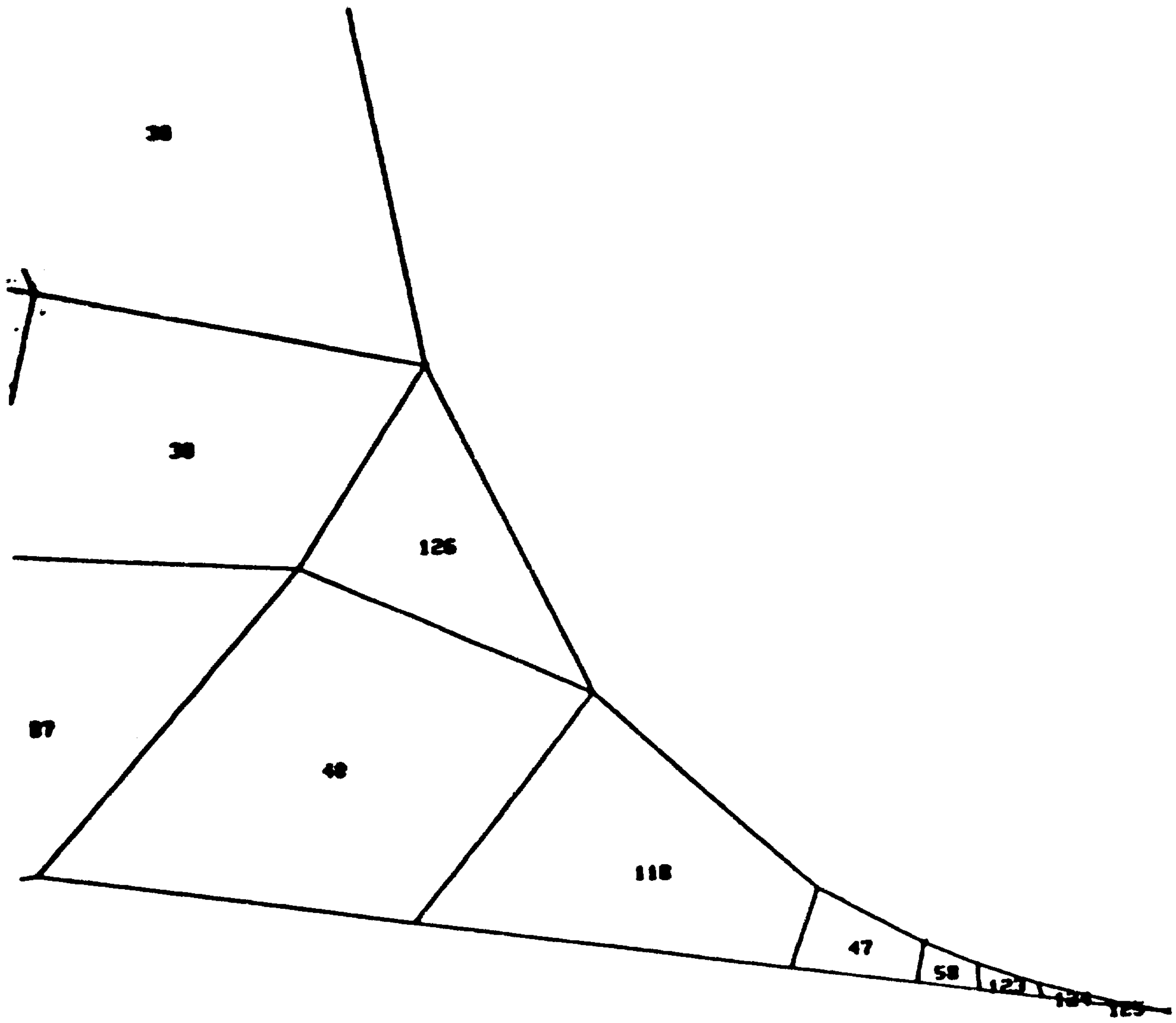

Figure 4B Modified End Radius Configuration
Element Numbers at the End

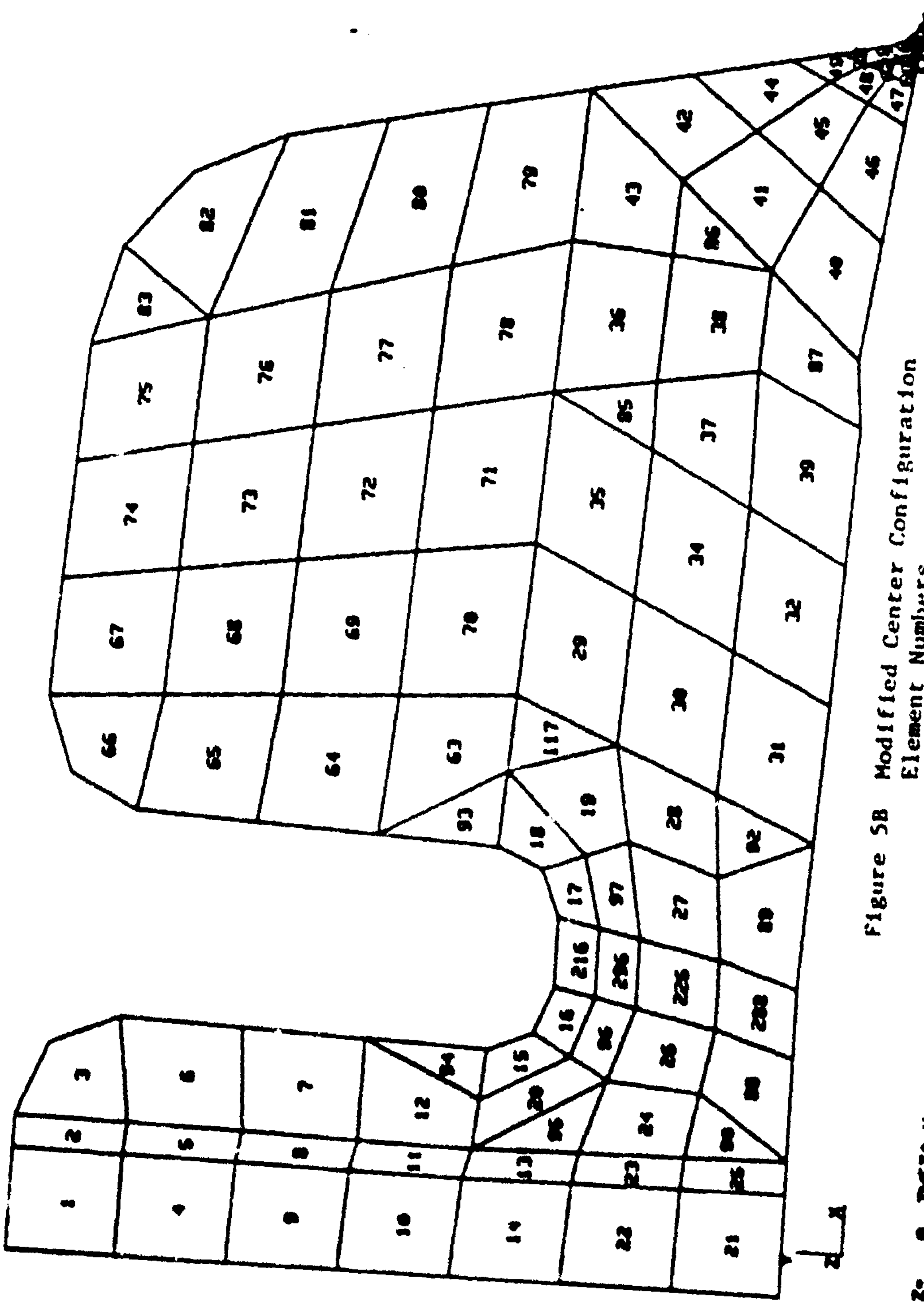

Figure 5B Modified Center Configuration
Element Numbers

THETA Z= 0. THETA Y= 0. THETA X= 0.